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IRON-FOUNDING

Frontispiece

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PITMAN'S COMMON COMMODITIES
AND INDUSTRIES

IRON-FOUNDING

BY

B. WHITELEY

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PREFACE

THE art and science of moulding is one of the corner stones upon which the edifice of engineering rests. This little volume is an attempt to place before those who are not intimately acquainted with the interior of a moulding shop some idea of the material and appliances used, together with the methods of manufacture and the principles underlying the whole. Nothing beyond a general survey of a subject so vast could be attempted, and very much interesting detail has of necessity been omitted in the endeavour to give an outline of a business which touches life at so many points.

The author wishes to acknowledge his indebtedness to previous workers, and gratefully acknowledges the assistance he has received from Messrs. Longmuir and McWilliams' "General Foundry Practice"; Mr. W. H. Hatfield's "Cast Iron in the Light of Recent Research"; Mr. E. L. Rhead's "Principles and Practices of Ironfounding"; Prof. Turner's "Lectures on Ironfounding"; Anderson's "Strength of Materials"; and the Journals of the Iron and Steel Inst., and the Inst. of British Foundrymen. Acknowledgment is also made of the kindness of The Campbell Gas Engine Co., Ltd., Messrs. Geo. Green & Co., Messrs. Vaughan & Co., Messrs The Britannia Foundry Co., Ltd., Messrs. The Blackfriars Foundry Requisite & Equipment Co., Ltd., and Mr. J. Horner, in supplying material for the illustration of this work.

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CHAPTER I

HISTORICAL

In prehistoric ages man made his tools and weapons of stone, usually flint. These at first were roughly chipped into shape, but as time went on they were gradually improved being made in greater variety and of better shape, till in the latter part of that era they were both highly finished and polished. Toward the end of the Stone Age, some great unknown discoverer commenced a new era by introducing the making of copper implements, probably at first by hammering the copper out of the ore. As time progressed, the art of melting copper and tin was discovered, and bronze tools superseded the implements of stone, until in the latter years of the Bronze Age articles were made of a composition almost identical with that of the gun-metal of the present time. During the latter bronze period, probably at some time antecedent to the time of written history, the use of iron was discovered.

It is possible that the first iron used was meteoric, being pieces broken from meteorites and hammered into shape. In a paper read before the Iron and Steel Institute in September, 1916, by Mr. G. F. Zimmer, he discussed the probability of this, and stated that the Eskimos of North America possessed knives made of small pieces of iron probably obtained in this way, and

fitted into bone or wooden handles, and that tribes of Indians in South America tipped their arrows with similar material, while at the same time the much more highly-civilized Aztecs of Central America were still in the Bronze Age, and their weapons and utensils at the time of their conquest by the Spaniards were made of bronze, they having no knowledge of the manufacture of iron.

When the use of iron was introduced can only be conjectured, and in what manner and under what conditions the discovery of the power to obtain it from the ore was made is absolutely unknown. The first mention of the use of iron is in the Bible, where Tubal Cain is mentioned as "an instructor of every artificer in brass and iron." At this period, the art of working in iron must have been fairly widespread, and further references in the Scriptures and other ancient writings prove the antiquity of the industry.

For long centuries, the process of the reduction of the metal from the ore must have been on the same lines as in later days were practised by the natives of Central Africa and India, where by the use of charcoal and a blowpipe of some kind, the ore was reduced, the slag run away, and the spongy metallic mass remaining was beaten into form as a piece of wrought iron. It must be borne in mind that the power to melt the metal had not yet been discovered, and that the first, and for many centuries the only, workers in iron were the smiths. So that they might obtain the draught necessary to produce the requisite heat to reduce their ore, the ancient smelters sometimes took advantage of natural draughts and built their furnaces on windy hillsides and glens. The invention of mechanical means of producing draught in the form of bellows, water-blowers, and the like, was followed in due course

by an increase in the size of the ancient smelting furnace, and there is every probability, owing to the increasing temperatures which could be obtained by the use of these mechanical blowers, that cast iron had been accidentally produced, and it is also very likely that having been produced, it was thrown away as useless, its hard and brittle nature rendering it unfit for the purposes of the smith.

The middle of the fourteenth century appears to be about the time when cast iron was first produced as such in England, though it is stated that it had been known almost a century earlier. So far as can be ascertained it seems to have been used principally in the manufacture of cannon, and the growth in size of these implements of warfare led to the construction of still larger furnaces and the consequent development of the blast furnace. Early in the sixteenth century cast iron cannon of large size—up to ten thousand pounds in weight—were being made in England, and the industry was being largely developed in and around Sussex. As the value of the material became more widely known and probably also as beds of ore were discovered in various places, furnaces were started in other parts of the country, and iron cannon were exported to the Continent. The prosperity of the industry in this country soon brought the smelter into difficulties. In the course of years the increasing amount of charcoal required for the use of the smelting furnaces was causing the rapid destruction of the forests in different parts of England, and so, in the early years of the seventeenth century, an Act of Parliament was passed restricting the cutting of trees for the making of charcoal for iron smelting to the forests of Sussex and the adjoining districts, and there limiting the size of the wood which could be utilized, which

restriction very prejudicially affected the growing industry. The iron smelters of the Continent, provided with an almost inexhaustible supply of fuel in their enormous forests, still continued their method of manufacture by the use of charcoal for a very long period. But the English smelters, driven either to discover some new fuel for their industry or else allow it to perish, experimented with coal which was then coming into use, and Dud Dudley in England and Sir George Hay in Scotland produced iron from the ore by means of coal. Raw coal being by no means a perfect substitute for charcoal, Dudley experimented for some time on the lines of obtaining from coal a substance more resembling charcoal, but a series of untoward events led to the abandonment of the project, and for over a century little progress seems to have been made, and it was not till nearly the middle of the eighteenth century, when Abraham Darby successfully manufactured coke, that the industry took another step forward. When steam had been harnessed, it was applied to the production of blast for the furnaces, which arrangement was first made near the end of the eighteenth century, and the increased blast allowed of the building of larger furnaces with consequent increased production. The use of the hot blast introduced by Neilson in the third decade of the nineteenth century sent forward the production by leaps and bounds. The increased production and consequent cheapening of the material caused a great enlargement in the number of uses to which cast iron could be applied and foundries sprang up in all parts of the country, till now there are comparatively few towns or even villages of any considerable size that do not possess a foundry.

Both the Blast Furnace and the Cupola have been very slowly evolved from the Stuckofen or High

Bloomery, used in the Middle Ages for the reduction of the iron ore, which furnace in its turn had gradually developed from the original blowpipe furnace. But whereas in the old furnaces the temperature during the process of reduction was not sufficiently high to melt the metal, but only to cause it to become a spongy mass, which being in constant contact with the flames from the fuel had most of its carbon oxidized out of it leaving an almost pure mass of iron, with the exception that portions of slag were mingled with it, certain developments and alterations in the modern furnace result in the production of a metal of different composition and with totally distinct mechanical properties. These developments may be said to consist chiefly in the more highly-mechanicalized production of the blast, resulting in much higher temperatures being attained, causing the complete fusion of the metal; the extension of the furnace stack in an upward direction, allowing of a continuous process if required; and the provision of a well below the combustion zone in which the metal, melted and containing in solution large quantities of carbon, may be protected from the oxidizing influence of the flames by a layer of molten slag.

During recent years the greatest advances in foundry practice have been in the way of more economical melting of the metal in the cupola; in the improvements in moulding practice brought about by the requirements of the machine and engine-maker; in the introduction of machines for the making of cores and moulds, and in the increasingly improved metal produced, as the result of the investigations of the chemist and metallurgist into the composition of the metal and the mechanism of the changes which take place within it. These investigations are still in their infancy, but as the results obtained by investigators

in various parts of the world become known, the reasons for foundry practices which have become established as the result of long experience are discovered, and it may be confidently expected that as this knowledge becomes deepened and widened, constantly improving methods of working and increasingly better material will be the issue.

CHAPTER II

INTRODUCTORY

THE principles and practices involved in the production of articles, variously formed and shaped, by filling properly shaped cavities or moulds with molten iron constitute what is known as iron-founding. In dealing with this question therefore it will be obvious that consideration will be required to be given to the metal of which the articles are made, to the furnaces which are required to reduce the metal to the molten condition, to the principles involved and the materials and methods used in the preparation of the moulds or cavities into which the metal has to be poured, to the manner in which the metal has to be handled, and to the various developments which have taken place in the industry.

Articles made of cast iron enter very largely into the life of every individual living in a civilized community. In the home, firegrates, pans, baths, bedsteads, and other household utensils are to a large extent made of this material, and in the workshop and factory, on the farm, and in almost every sphere of labour, tools and implements are used which are either wholly or partly built up of this same material, cast iron; while when travel is undertaken, especially by the newer methods of motoring and flying, it often happens that portions of the main parts of the mechanism, e.g. the cylinder and piston of the engine, are largely or wholly composed of cast iron.

The amount of cast iron which is used in the British Isles reaches an enormous figure, and the number of tons of iron used in the manufacture of cast iron during the year 1918 was upwards of one million.

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In a large percentage of castings produced even to-day the material is not required to possess any special physical properties or to fulfil any special requirements beyond that it shall sufficiently fill all the interstices of intricate moulds, and that the castings shall be sound, free from all defects such as blowholes and shrinkage defects, shall have perfect surface finish, and be of proper dimensions; e.g. pans, kettles, water-pipes, etc.

In the remainder of the castings, which for the most part consist of those castings for internal combustion engines, and other engine and prime mover parts, there are usually other requirements to be considered and special physical properties to be obtained. It may be necessary for the cast iron to have a strength which is known to be greater than a predetermined minimum; or it may be required to resist the high temperature and pressure conditions such as obtain in diesel engine cylinders. The introduction of the internal combustion engine, and especially of the lighter type of auto-car and aircraft engine, has possibly been instrumental in bringing about the tremendous improvement in the general and physical properties of cast iron during recent years. These improvements extend beyond the actual metallurgical questions involved in the quality of the material to the technique of melting, moulding, and foundry management. As an example of the improvement of cast iron from the metallurgical side, one need only compare the position to-day with that of a few years ago. Writing in 1892 Sir John Anderson stated, "The average ultimate tenacity of ordinary cast iron is about 7 tons (per sq. in.) . . . The quality used for guns should have a tenacity of not less than 10 tons per sq. in." About twenty-five years later the requirement in the recent Air Board specifications for

castings used in the manufacture of aircraft cylinders, and other material required for aeroplane engine construction is 15 tons per sq. in. tensile strength.

It is most necessary that a clear idea of the real meaning of the term cast iron should be obtained. All the varieties of metal known as steel, wrought iron and cast iron are produced from the iron ore, the difference in their qualities being caused by the varying treatment that the metal undergoes in the course of its production. The following table briefly illustrates the different processes through which iron passes from its initial production from the ore to each of the three commercial products previously mentioned.

Iron Ore
smelted in the Blast Furnace
gives
Pig Iron.

Puddled gives Wrought Iron.	Remelted and cast direct into castings gives Cast Iron.	Oxidized or diluted so as to have a much lower carbon content than Cast Iron gives Steel.

In the iron ore, the iron occurs in combination and mixed with a variety of substances. The operation of separating the iron from all these contaminating materials is known as smelting. This smelting operation is usually carried out in the modern blast furnace in which the ore, previously calcined, is heated to a high temperature by means of coke or coal which is burnt by the introduction into the furnace of a large current or blast of air.

The modern blast furnace is a tall cylindrical structure about 60 to 90 ft. in height and 20 to 30 ft. in diameter.

The ore, which is previously calcined or heated to a high temperature in calcining kilns exactly similar to lime-burning kilns, is introduced into the blast furnace at the top along with the requisite proportions of fuel and limestone flux. The object of the preliminary calcining operations is to effect a concentration of the ore by the removal of moisture and the volatile carbonaceous materials which are frequently present in the ore. As the whole of the charge descends the stack it gradually approaches the hottest zone which is very near the point at which the blast is introduced, and as a result of a complex series of chemical reactions between the ore, the fuel and the limestone, metallic iron is set free, and the earthy impurities for the most part combine with the limestone flux forming a molten substance of a vitreous or glass-like nature when cold known as "slag." The molten iron liberated collects in the bottom of the furnace or hearth from whence it is tapped out and cast into channels arranged in the floor near the furnace. The resulting bars of cold metal, about 4 to 5 ft. in length and of a  shaped section, are known as pig iron. The slag which floats on the top of the molten metal in the furnace is tapped out from a higher level than the iron.

In the early days of blast furnace practice, the hot gases were allowed to escape from the top or throat of the furnace. It is customary nowadays to utilize these gases for the purposes of boiler firing, driving the blowing engines, etc. The gases are cooled in the first place, and the heat abstracted from them is utilized in pre-heating the blast. Pig iron produced in such furnaces is known as hot blast, while that produced in furnaces not pre-heating the blast is known as cold blast iron.

The molten metal collected at the bottom of the

furnace and cast into pigs contains, in addition to iron, large quantities of impurities which are chiefly the elements carbon, silicon, manganese, sulphur and phosphorus. In addition, traces of rarer elements, such as copper and titanium are frequently found, and even minute traces of gold and silver have been detected. This is the cast iron of commerce. We may therefore define cast iron as metallic iron, essentially containing large quantities of carbon along with other elements chiefly silicon, manganese, sulphur and phosphorus.

The amount of pig iron smelted in Great Britain is about 9 million tons per annum, and of this 1 million are used in the manufacture of cast iron articles. It will be readily understood that pig iron produced in the modern blast furnace will not be fixed in its composition as so many variable conditions enter into the process of manufacture. The temperature of the blast, the varying composition of the ore, and the variable quantity of the limestone which may be used as flux, all affect the final product of the blast furnace. Furnace-men realize this and attempt to classify their products in various grades. This grading is done principally by examination of the fracture of the pig, and according to the appearance of this fracture the pigs are assorted into numbered grades. No. 1 pig is the greyest and softest of the irons, and is very crystalline, showing large flakes of carbon in the form of graphite, and is only used in iron-founding for light and ornamental work where strength is not a prime necessity. No. 2 pig is somewhat more closely grained than No. 1 with a slightly less quantity of graphite. No. 3 is still closer grained, and while still soft, is harder and stronger than the preceding, and the graphite is not so easily distinguishable. No. 4 is often divided

into two classes, No. 4 foundry and No. 4 forge. It is whiter than the previous classes, being strong and very finely grained. Some makers frequently have a No. 5 grade which is harder and closer than No. 4 and nearly approaches mottled. White iron is intensely hard and brittle, very crystalline, and shows no trace of graphite in the fracture. Intermediate between the white and grey irons comes mottled iron, which is a kind of transition stage between white and grey irons. The fracture is grey mottled or white mottled according as to whether grey iron or white iron predominates in the fracture.

There can be no doubt that by long practice and experience it is possible to some extent to judge of the quality and value of the pig iron by its fracture. But when the number of variable factors which enter into the manufacture and composition of pig iron are considered, among which may be noted the variations in the composition of the ore, the coke and the limestone used in the blast furnace, the different rates of cooling which may possibly occur, and the resulting alterations in the chemical composition of the pig iron, some elements producing one effect and others precisely opposite effects in the iron, it will be obvious that an iron-founder basing his practice purely upon judgment by fracture will, on many occasions, obtain results in his working which are by no means satisfactory, and so it has been found necessary to assist this judgment by chemical analysis. Analysis proves that the same numbers of pig iron coming from different districts vary as to the percentages of the elements in the iron, and that even in the products of any district considerable variation in composition occurs in pigs that are graded by fracture into any particular number. This of course explains some of the otherwise inexplicable failures which have occurred in foundry practice when absolute

reliance has been placed upon grading by fracture, and suggests that in place of the rule of thumb method of grading heretofore adopted, a system of grading by analysis should be substituted. Several attempts have been made to formulate such a scheme which would satisfy the requirements of the iron-founder and be acceptable to the blast furnaceman. The latest attempt was made by the Iron and Steel Institute in 1910, but the findings of the committee appointed for this purpose left matters much as they were, and the grading of pig iron still remains in this unsatisfactory position.

The following series of analyses of pig irons give an idea of the percentages of the various elements present in commercial cast iron of a phosphoric type. It will be observed that the amount of graphite in each succeeding number is a gradually decreasing quantity, till in the sample of white iron it is noticeable by its entire absence; and that while the other elements remain fairly constant or vary irregularly in quantity, the silicon also, as well as the graphitic carbon, diminishes in each successive sample. It must be remembered, as has been pointed out, that the various numbers even from the same blast furnace are not constant in their composition, and the only way in which this variation can be discovered is by analysis.

	No. 1.	No. 2.	No. 3.	No. 5.	White Iron.
	%	%	%	%	%
Combined Carbon	·08	·20	·48	·80	3·05
Graphite	3·2	3·16	3·12	2·93	—
Total Carbon	3·28	3·36	3·60	3·73	3·05
Silicon	3·5	2·9	2·59	1·50	·67
Manganese	·68	·62	·60	·60	·42
Phosphorus	1·67	1·69	1·59	1·17	1·60
Sulphur	·05	·06	·08	·145	·4

Further, in connection with the classification of pig

irons special terms are adopted in addition to grading by numbers. For example, irons which are smelted from ore consisting largely of oxide of iron and which are very low in phosphorus content are classed under the name of hematite iron, while those high phosphorus, low silicon irons which are largely produced for use in basic steel furnaces are termed basic pigs. The Cleveland district in which is produced a phosphoric iron from ores which contain mainly carbonate of iron, gives its name to the iron smelted under the term Cleveland pig; whereas in the Staffordshire district, where the puddling of iron is largely carried on, the ore and material which has formed the bed of puddling furnaces, is smelted into pig iron known as cinder pig. In contradistinction to this, those Staffordshire irons smelted from ore without any admixture of the puddling cinder are known as All Mine pig. Swedish iron as its name implies is smelted in Sweden from ores which are largely composed of the magnetic oxide of iron, and is the purest form of iron manufactured. Originally, all pig irons were smelted by means of charcoal, but now other fuels are used, and the little that is still manufactured with the original form of fuel, is distinguished as charcoal iron. Pig irons which have a high silicon content, say of over 4 per cent, show a very distinctive fracture, and because of this are designated silky pigs.

CHAPTER III

THE METAL

As has been mentioned in the preceding chapter, cast iron is the carburized metal which is the product of the modern blast furnace, and which, as commercially used, also contains percentages of silicon, manganese, sulphur and phosphorus. This cast iron exists in two distinct forms; first, as a very hard and brittle material, showing on breaking a whitish fracture, unmachinable owing to its hardness, which is so great that glass can be scratched with it; and second, as a comparatively soft material, easily machined, and having a grey fracture on breaking. The first form of the material is commercially known as white iron, and the second as grey iron. It will be obvious that white iron is a very unsuitable material in which to produce castings. Its great brittleness, and the impossibility of machining because of its great hardness, make it of no value whatever, except in the special case of malleable castings which are rendered machinable by subsequent treatment, and which are dealt with in a later chapter, and as a consequence the aim of the ordinary foundryman is to produce castings in the softer material.

If the fractures of some of the more coarsely-grained irons be examined, the presence of carbon in the form of graphite will be revealed, and in certain samples it is possible, on account of the comparatively large size of the grains, to detach the carbon by the aid of a pair of forceps. The rubbing of grey iron turnings on the palm of the hand will produce a black mark characteristic of graphite or plumbago. If a white iron be similarly examined no trace of graphite can be detected,

and so it becomes obvious that the differences between the two classes of metal are due to the presence or absence of the graphite in this free state.

As a result of the investigations of some of the most distinguished chemists and metallurgists, it has been demonstrated that both in the white and grey types of metal, there is, as a rule, approximately the same quantity of carbon present, but that while in the grey iron some portion of this exists as graphite, giving the grey appearance to the metal, in the white iron the carbon exists in the form of a chemical combination of carbon and iron known as carbide of iron, dissolved in the metal itself. In the course of their investigations into the structure and composition of the metal, these metallurgists have established that this dissolved carbon is retained in this form in the iron very largely as a result of the comparatively quick rate of cooling from the molten state, and that if the white iron were cooled down sufficiently slowly it would be found to contain graphite, and to break with a greyish fracture, that is, it would no longer be white iron.

It has also been further proved that certain of the other elements present in commercial cast iron have an effect on the final composition of the metal, and influence the production of graphite either by retarding or increasing it in a more or less similar way to that in which it is effected by the rate of cooling. For example, it was shown by Prof. Turner in 1884–86 that the presence of silicon in increasingly large quantities up to a certain maximum results in the gradual increase of carbon in the form of graphite, and a corresponding reduction of the carbon present in the combined dissolved form of carbide of iron.

In an opposite manner, but not to so marked a degree in the percentages usually met with in commercial

cast iron, the presence of manganese and sulphur have a tendency to prevent the formation of graphite, and to cause the carbon content of the metal to persist in the iron in its combined state. The remaining element commonly present, phosphorus, appears to have little or no influence on the condition of the carbon, and from this point of view may therefore be neglected. Though phosphorus has little influence on the condition of the carbon, it exerts a considerable influence on the melting point of cast iron. Dr. Stead in his classical research on the iron-carbon-phosphorus system shows that phosphorus exists in the iron as a phosphide of iron very similar in nature to the carbide of iron. It is soluble in the molten metal, and entering into solution, reduces the melting point of the melting to a considerably lower figure than does the carbon. He also showed that with the percentages of phosphorus usually found in Cleveland iron, the melting point of cast iron is reduced to somewhere in the neighbourhood of 980° C.

It will be readily perceived from these facts that the utility of phosphorus in commercial cast iron is the result of this lower melting point, so that at the same temperature a high phosphorus iron is considerably more fluid than a low phosphorus iron owing to the difference in their final solidification points.

It will thus be readily appreciated that between the maximum hardness and the maximum softness of the metal there exists a great range of variation in the properties of cast iron, and that these variations depend to a very large extent on the quantity of graphitic carbon present in the various samples of material, and that it follows that by suitably adjusting the amounts or percentages of the various elements controlling the formation of carbon in the form of graphite, it is possible,

provided that the rate of cooling remains constant, to produce cast iron which contains varying quantities of carbon in the combined and free graphitic states, which in their turn represent different degrees of hardness in the metal.

In addition, the presence of graphite in cast iron, besides affecting the colour, the hardness and the machinability of the metal, is responsible for another important feature. The suitability of cast iron for making castings, apart from the point of view of cost, is chiefly due to its low total shrinkage on cooling down from the molten to the solid state. The reason for this will be readily ascribed to the formation of the graphite in the grey iron. The graphite itself is considerably greater in volume than the carbide of iron from which it originates, and hence the lower shrinkage.

An interesting series of experiments was devised by Prof. Turner for the purpose of demonstrating the smaller shrinkage of grey cast iron as compared with that of white iron. Bars of T-shaped form were cast, the T end being rigidly fixed, while an iron pin was cast into the metal at the opposite end, and connected with an extensometer for the purpose of registering any change in measurement which might take place in the bar while changing from the liquid to the solid state. This change was read off from the instrument and the curves drawn, and the difference in these curves is explainable by the formation of the graphite in the grey metal as mentioned above.

It will be readily perceived that in considering cast iron from the point of view of its resistance to fracture when subjected to stresses of different types, that the structural arrangement of the various constituents will exert considerable influence on its behaviour in this connection. When examined under the microscope,

grey cast iron is found to be a complex mixture of a number of constituents embedded in each other, the most important of which are the free or graphitic carbon and the phosphide constituent. These are shown

FIG. 1.

in the microphotograph Fig. 1 embedded in a matrix of iron together with the portion of carbon in the combined and dissolved condition micrographically known as ferrite and pearlite respectively. The whole of this structure in this particular case will be seen to be cut up by the numerous plates of graphite, which, it will be easily understood, form lines of weakness which may

readily become a connected path through which fracture may traverse across the particular specimen when it is subjected to a particular type of stress. In addition to this, the phosphide constituent is an extremely

FIG. 2.

hard and brittle substance, nearly as hard as the combined carbon itself, and in its turn it may exert its quota of influence on the brittleness of any particular specimen when subjected to stress influences, according as to whether the quantity of this constituent is large or small, and also according to the ratio of the amount of this constituent compared with the amount of

graphite. Further than this, it will be readily understood that the actual structural arrangement of these separate constituents, apart from any consideration of their quantity, will exert considerable influence on the strength of a particular sample when subjected to stress. In the microphotograph Fig. 2, which from the point of view of composition is almost identical with the specimen represented in the previous photograph, it will be noticed that the free carbon is in a more finely divided condition, and the phosphide constituent is more regularly distributed, both of which offer less opportunity for the formation of lines of weakness across the specimen through which fracture may travel when stress is applied. This example will be sufficient to illustrate the immense importance of the structural constitution of cast iron as opposed to the chemical constitution. This structural constitution and the factors controlling it have been extensively studied by metallurgists and considerable information has been accumulated which enables the best particular structure for any given type of work to be selected, and also enables means to be taken to obtain the desired structure in the foundry. It should however be appreciated that the laws or factors governing the structural constitution cannot be definitely stated on the lines of the laws governing the chemical constitution, which are simple laws of mixtures, and that much work remains to be done before this state of affairs is arrived at. Considerable advance has, however, been made in recent years, and in certain particular products the control of the structural constitution is being carried out in a practical manner.

CHAPTER IV

FURNACE MIXTURES

In actual foundry practice castings are rarely if ever made by melting one brand or grade of pig iron only. Various conditions, both of a technical and economic nature, arise which render it more or less impossible for this to be done. The fact that various makes and grades of pig iron vary in price, and that in addition there is usually a large quantity of scrap cast iron in the form of disused and broken-up machinery at disposal, for the most part lower in price than that of the pig iron, and that in the actual foundry itself scrap is made daily in the shape of waster castings, gate runners, riser and feeder heads, render it necessary, for economical reasons and also in order to maintain a consistent quality of metal, to charge varying proportions of the different classes of metal enumerated above into the cupola. These charges constitute what is known as cupola mixtures. Furthermore, when making castings complying with particular engineering specifications it is also necessary that predetermined quantities of the varying grades of iron at the disposal of the foundry management be charged into the furnace.

The methods of controlling foundry mixtures can be divided into two classes, viz., (*a*) the old-fashioned rule-of-thumb method in which the character of the final metal is controlled by mixing varying proportions of pig iron and scrap according to the openness or closeness of the fracture of the pig iron at the disposal of the foundry foreman. This method which is usually spoken of as "Fracture Control," consists essentially

of mixing a large quantity of close-grained scrap with an open-grained pig iron, or a small quantity of close-grained scrap with a closely-grained pig iron. The exact quantity of scrap used, according to the openness or closeness of the grain of the pig iron, is a matter which lies entirely in the hands of the foundry foreman, and it is charitable to suppose that his previous experience is sufficient to enable him to obtain fairly satisfactory results. In view of the increased demand for the production of higher and more uniform grades of castings this old method, which is obviously defective, is gradually falling into disuse, and is being substituted by (*b*) the more rational method of controlling the character of the final product by the composition of the materials charged into the cupola.

For the production of castings in which the ordinary requirements of the machine shop have to be taken into consideration, the only qualities required are that the metal shall be capable of being machined at the maximum speed, and shall give castings free from shrinkage, blowholes, and other defects, and also correct both as to shape and general dimensions. It will be readily appreciated by what has been said before with regard to the constitution of cast iron, that these factors in so far as the metal is concerned, depend almost entirely upon the extent of the graphite precipitation. This in its turn, with metal of any given composition, will depend upon the rate of cooling, or the reciprocal of this, the thickness of the casting. In order to produce these properties uniformly in all thicknesses of castings, it is usual to modify the silicon content, which, presuming the rest of the composition remains constant, modifies the extent of the graphitization.

The following table has been constructed by the

late Mr. G. Hailstone giving the varying silicon content for varying thicknesses of castings—

Thickness of Metal.	Silicon.	Sulphur.	Phosphorus	Manganese.
Inches.	%	%	%	%
0·25	2·70	0·05	1.0	0·4
0·50	2·40	0·06	1·1	0·4
0·75	2·40	0·07	1·2	0·5
1·00	2·00	0·08	1·0	0·6
1·50	1·75	0·10	0·8	0·7
2·00	1·50	0·11	0·75	0·7
2·50 to 3·00	1·25	0·12	0·60	0·8

According to the particular class of work in the foundry, the superintendent or metallurgist decides primarily on the silicon content of the iron most suitable. It is assumed that the chemical composition of the raw materials in the shape of pig iron and scrap at the disposal of the foundry is regularly obtained either from the suppliers or in the foundry's own laboratory, and by a kind of trial and error method a sort of provisional mixture is devised. It will be appreciated that the governing factors in devising a provisional mixture along these lines are largely of an economic nature, and depend upon prices and quantities of material at disposal, and the readiness with which the stock may be replaced.

The mixture can be calculated out in the following manner. Assuming that the chemical composition of the materials at the disposal of the foundry are—

	Pig Iron A.	Pig Iron B.	Machine Scrap.	Foundry Scrap.
	%	%	%	%
Total Carbon .	3·9	3·6	3·25	3·00
Silicon . .	3·25	1·7	2·5	2·25
Manganese .	1·25	0·45	0·6	0·75
Sulphur . .	0·07	0·04	0·11	0·15
Phosphorus .	1·25	1·50	1·00	1·10

imagine a mixture of 20 cwts. made up from the above in, say, the following proportions: 4 cwts. A, 6 cwts. B, and 5 cwts. of each kind of scrap. Multiply the percentage of each constituent by the weight in cwts.—

Proposed Mixture.	Total Carbon.	Silicon.	Manganese.	Sulphur.	Phosphorus.
cwts.					
A.—4	15·6	13·0	5·0	·28	5·0
B.—6	21·6	10·2	2·7	·24	9·0
M.S —5	16·25	12·5	3·0	·55	5·0
F.S.—5	15·0	11·25	3·75	·75	5·5
20	68·45	46·95	14·45	1·82	24·5
	3·42	2·34	·72	·091	1·22

Total and average by dividing by 20 (the total number of cwts.).

On remelting the iron according to the mixture slight modifications in the mixture take place owing to slight losses or increases in the various constituents taking place in the cupola. The only constituent which is modified to any extent warranting serious consideration is the silicon which undergoes loss. This loss is readily found by experience in any particular cupola, and can easily be allowed for in the calculations. As a rule, it is usually in the neighbourhood of ·25 per cent. So that, in the example already quoted, the final composition would be—

	%	
Total Carbon	3·42	
Silicon	2·09	(2·34 – ·25)
Manganese	·72	
Sulphur	·091	
Phosphorus	1·22	

If this composition be not exactly suitable for the purpose required, an increase or decrease in the amount of any constituent may be obtained by varying the

weights of the particular class of material which contains more or less than the average already obtained. The same method is followed in the calculation of mixtures for fulfilling special requirements.

For certain special purposes alloys are used containing abnormal percentages of particular elements which, strictly speaking, in the majority of cases do not belong to the cast iron family, but which are so intimately connected with iron foundry practice as to be worthy of special mention. Among the most important of these is a special acid-resisting alloy which is extensively used in the manufacture of chemical plant, and which in commerce goes under a variety of names—tantiron, corros iron, iron-ak, etc. This iron is essentially a cast iron containing large quantities of silicon, and a typical analysis is given below.

CHEMICAL COMPOSITION OF HIGH SILICON NON-CORRODIBLE ALLOY FOR CHEMICAL PLANT.

	%
Total Carbon	0·57
Silicon	15·43
Manganese	0·64
Phosphorus	0·44

This alloy, which is a hard unmachinable metal, resists the attack of concentrated hydrochloric and nitric acids, and is largely used in the manufacture of plant for chemical works in the form of retorts, pans, valves, pumps and other chemical engineering appliances. It is prepared in the cupola by melting foundry pig irons with the requisite quantity of a high silicon iron alloy known as " Ferro-Silicon." In casting this metal, which is a white iron, precautions have to be taken similar to those taken in producing white iron castings for the production of malleable castings, which are dealt with in a later chapter.

Other elements have been added to grey cast iron

with the object of obtaining special properties. The most important of these are tin, nickel, chromium and copper. The two former have been used for the purpose of producing a hard material capable of resisting wear in heavy duty work, such as shell-piercing tools and limit gauges. Chromium and copper have been added with the object of resisting the effect of heat and atmospheric corrosion respectively.

In addition to these, the elements aluminium, titanium and vanadium have been added in small quantities, and these elements are claimed to have a cleansing action on the metal, reducing its liability to blowholes and other dirt inclusions.

Of late years, there has been an extending adoption of the use of steel scrap in cast iron foundry mixtures. These mixtures have somewhat unfortunately been given the distinguishing title of "semi steel," which, in so far as there is the tendency for the term to convey the impression that the physical properties of this material lie midway between those of cast iron and steel, is misleading. This idea is not correct, and should any special name be required for such mixtures, it would be preferable to designate them as "Steel Mixture Irons." It is stated that the use of steel scrap increases generally the properties of the cast iron, and this is undoubtedly true in so far as its use effects a reduction in the quantity of silicon and phosphorus in the final iron, according to the amount of steel scrap used. Viewed from this standpoint the use of steel scrap may be compared to the use of a low silicon hematite or low phosphoric cold blast pig iron. The introduction of steel scrap along with grey iron into the cupola mixture does not as a rule involve any reduction of the total carbon content in the final iron. The reason for this will be appreciated when the mechanism of its

melting in the cupola is considered. When it is remembered that the melting point of steel is at a temperature approaching 1500° C. (about 2700° F.) and that the maximum temperature of the cupola seldom exceeds 1400° C. (about 2500° F.), the question as to how steel readily melts in the cupola is a very natural one. It should be remembered that steel is a low carbon iron alloy containing as a rule about ·5 per cent combined carbon. When this material is charged into the cupola, and becomes heated in direct contact with the coke and carbonaceous gases in the cupola, the steel rapidly absorbs carbon even whilst in the solid state, exactly as in the manner of the case-hardening of steel. The direct result of the absorption of carbon is a lowering of the melting point of the metal, until when it has absorbed about 1·5 per cent of carbon its melting point is reduced to a figure within the range of the cupola temperature. It then rapidly melts, and in melting absorbs considerably more carbon, until it becomes saturated with carbon for the particular temperature of the cupola, which saturation point is round about 3 per cent to 3·5 per cent carbon. Obviously therefore, there is no reduction in the carbon content of the final metal.

CHAPTER V

THE CUPOLA AND OTHER FURNACES

VERY frequently castings are produced from molten metal direct from the blast furnace. This procedure, in that it eliminates the casting of pig iron and its subsequent remelting in the foundry results in a considerable economy of heat which would otherwise be lost by radiation from the pig beds, and in economy of labour, time and transport. As a general rule, however, the castings made in this way are those extremely large castings, and also those simple castings, of which huge quantities are required for commercial purposes. For example, pipes and large cast iron tanks are made at Staveley, Stanton, Holwell and other blast furnace plants.

For the majority of purposes, however, castings are usually made in separate foundries, most of which are situated at some distance from the blast furnaces. Under these circumstances the pig iron is delivered by rail, and obviously before castings can be produced it is necessary to remelt the material.

There are several types of furnaces which may be used for the remelting of the pig for casting purposes in the iron-foundry. The most common of these is a tall cylindrical furnace which is technically known as the cupola furnace. Broadly speaking, the cupola might be likened unto a miniature blast furnace. It consists of a tall, narrow, cylindrical metal shell, usually of boiler plate, lined up on the inside with refractory material, generally silica brick and ganister. The cylindrical stack is set up on end, the bottom end being totally enclosed, forming a hearth for the molten metal exactly as in the case of the blast furnace. On a level with the hearth a hole is provided through the

shell and lining for the purpose of tapping out the molten metal. At a somewhat higher level a similar hole is provided for the outlet of the slag which collects on the surface of the metal during melting. Also in the lower part of the furnace a door is arranged, by means of which the furnaceman can enter the furnace at the necessary times to attend to the repairing of the lining, this door being known as the "fettling door." At a somewhat higher level still, a series of holes is provided round the circumference of the stack for the introduction of the blast for melting purposes. The height of these holes, or tuyeres (twyers) as they are termed, is regulated by the amount of metal which it is proposed to gather in the hearth, sufficient room being left below the tuyeres to contain the quantity calculated upon. In modern furnaces which are as a rule designed by specialists in cupola construction, special attention is paid to the form and character of these tuyere holes through which the blast enters the furnace. As a general rule, the whole of these tuyeres are connected round the cupola by means of an air belt into which the blast is introduced from the fan or blower, and very frequently arrangements are provided whereby the entry of air through any particular tuyere hole may be separately controlled.

At a height of some 12 to 15 or more feet above the hearth a large hole fitted with a door is made, through which the material to be dealt with in the furnace is charged into it. To facilitate this, a platform or stage is built up to the cupola at about this height, and the material—fuel, metal and limestone—is brought on to the stage, generally by means of a hoist, but sometimes by a chain or bucket conveyor. A weighing machine should also form part of the equipment of the charging stage.

In a large proportion of cupolas, the bottom of the

cupola is solid, and the iron base plate is covered with sand or ganister well rammed down and shaped so as to incline all the molten metal to the tap hole. There is however an increasing tendency in modern practice to use cupolas with drop bottoms. In this type, the cupola is generally raised on four pillars or standards forming a kind of well under the base of the furnace. When the cast is over, the base plate, usually fixed in two pieces like swing doors, can be released, and the fuel and metal which remains in the cupola can be dropped on to the floor. In some cases the well is carried into the floor so as to lessen the risk of splashing molten metal when the base plate is released. This arrangement tends to economy in fuel consumption, as the unused fuel can be quenched and separated from the metal, and it allows of easier access to the interior of the cupola for the purpose of cleaning and repairing the lining, which is generally done before each heat.

When uniformity in the quality of the metal in any cast is required, the metal is often collected in a forehearth. This is an addition to the ordinary cupola of a receptacle into which the metal runs immediately it reaches the base of the furnace instead of collecting on the hearth. The value of this arrangement will be recognized when it is remembered that it is impossible to guarantee that any charge of metal in the cupola is exactly similar in composition to any other charge. But when these meltings of varied composition are mixed in the forehearth, the resulting metal is of the average composition of the series. In cases where the cupola is of the ordinary type, the same result can be obtained by collecting the metal in a large ladle and mixing.

In times past, when less interest in public health and cleanliness was taken than is now the case, cupolas

were allowed to pour into the atmosphere all the products of combustion with all the dust and sparks which were blown out of the furnace by the blast. This dust, when distributed over the neighbourhood, was an objectionable feature of the foundry, and now in most foundries situated in populous districts, an endeavour is made to reduce to the minimum this distribution of dust. For this purpose the top of the cupola has fixed upon it a spark arrester, which generally consists of a series of baffle plates so arranged as to deflect the gases while at the same time the sparks and dust strike the plates, and then either fall back into the furnace or descend into receptacles planned to receive them. The material taken out of the spark arrester consists of minute particles of coke, sand, limestone and oxide of iron, a typical analysis being given below. It may be of interest to note in passing that this waste product is considered to be of value as a fertilizer for certain crops, and is certainly of use in the lightening of heavy clay soils.

ANALYSIS OF CUPOLA DUST.

	%
Carbon . . .	47·44 (chiefly coke dust).
Silica . . .	37·75 (chiefly sand).
Iron Oxide . .	12·25
Lime. . . .	2·00
Magnesia . . .	0·56

The charging of the cupola in preparation for a melt is done in the following manner. Assuming that the lining of the furnace is in good condition, all parts from which material has been fluxed away during previous heatings having been repaired with ganister, a fire is lighted in the hearth, and upon this a bed of fuel is placed reaching up to some distance above the tuyere holes. On this is deposited a quantity of metal, followed by the necessary amount of limestone requisite to flux the ash of the fuel, and the sand carried by the

pig iron. This in turn is followed by layers of fuel, metal and limestone consecutively. The bed having become sufficiently lighted, the blast is turned on and the temperature is speedily raised to a high point, and melting commences. The charging is done through the charge hole, and the various charges are weighed before being dropped into the furnace. A by no means inconsiderable part of the successful working of a cupola depends upon the manner in which the charges are dropped into position in the furnace stack. The level and equal distribution of each constituent in its order helps to produce both better metal and more economical working. No rigid rule can be laid down as to the weight of each separate charge, this largely depending on the particular requirements of the foundry; but as each cupola seems to possess some degree of individuality, the man in charge of the melting operations notes the behaviour of the furnace with varying charges until he arrives at the conditions under which the best results are obtained, and having discovered these, he fixes them as his standard so as to make certain of the best and most economical working. The pressure of the blast must be sufficient to cause the air to penetrate to the centre of the furnace, and the amount of air delivered must be enough to promote the utmost complete combustion.

The blast is produced either by a fan or by some form of positive pressure blower, the size of which is of course dependent upon the size and capacity of the cupola, insufficient blast rendering the cupola slow in action and unable to work up to its highest capacity or to produce the hottest metal. Fig. 3 gives an idea of the principle of the Root's Blower, which is one of the main types of positive pressure blowers in general use.

One of the most important points in connection with

the successful working of the cupola furnace is the quality of the fuel used in it. Coke is the fuel used, and this should be as free from sulphur as possible, as this element, combining with the iron, is not desirable in the metal. It should also be of sufficiently firm texture as to be able to withstand the metal falling on it during the charging, without crushing. In burning

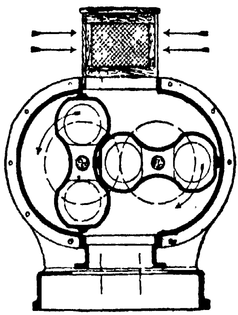

Fig. 3.

SECTION OF ROOT'S BLOWER

it should not leave a large quantity of ash, as this has to be fluxed away in the slag, necessitating the use of more limestone if the ash content of the coke be above normal. In addition, it should not hold large quantities of water, as the removal of the moisture requires heat which would otherwise be used in increasing the temperature of the charge in the furnace. The weight of coke in each separate charge is essentially determined by the weight and character of the metal portion of the charge, and should exactly replace, as it descends to the hearth, the coke which has been burnt away in the combustion zone at the tuyeres. The coke used is generally a metallurgical coke, which is produced by

subjecting powdered coal to a high temperature in special coking ovens. The coke produced is often in very large pieces, usually 3 to 4 cu. ft. in volume, and for foundry purposes it is necessary to reduce these to pieces of smaller uniform size. Special machinery is in use for breaking and screening this coke, and the resulting coke dust is frequently of value in the sand-mixing department of the foundry. The size and closeness of the packing of the coke in the charge is of importance, as the less the surface area of the coke in comparison with its volume, the less the amount of heat absorbed from the rising gases, and the slower the rate of combustion when burning commences.

Theoretically, the heat obtained by the complete combustion of 1 cwt. of coke, provided that the whole of the heat thus obtained is absorbed by the metal, is sufficient to melt about 2 tons of iron, but in actual practice this result can never be obtained and a consumption of 2 cwts. of coke per ton of metal melted is considered to be a good average. The difference between the theoretical value and actual consumption can be accounted for by losses which take place in various directions. In the first place this theoretical combustion occurs when the carbon is completely combined with oxygen to form carbon dioxide according to the equation, $C + 2O = CO_2$. But in the cupola combustion does not take place precisely in this way. Some of the carbon does combine with oxygen in the ratio mentioned, but a portion of the carbon only combines with oxygen in the proportion of one atom of carbon to one of oxygen forming carbon mon-oxide (CO), owing probably to the fact that a sufficient quantity of oxygen was not available at that particular spot. This gas may later combine with another atom of oxygen giving as result carbon dioxide. But in this

double reaction the number of British thermal units generated does not equal the number produced when carbon is directly combined with oxygen to give carbon dioxide. In the single reaction the number of British thermal units obtained per lb. is about 14,500, while in the reaction $C + O = CO$ only about 4,500 are generated, with a further addition of about the same number when the reaction $CO + O = CO_2$ takes place. There is here a loss of nearly a third of the possible amount of heat which should theoretically be developed. Various devices with respect to the introduction of air through variously shaped tuyeres, through double belts of tuyere holes, and through tuyeres arranged spirally round the cupola, have been tried in order to effect the more complete combustion of the coke, but it has not been found possible to eliminate the double reaction, and consequently the loss of heat owing to this cause is unavoidable. The flames which are seen issuing from the top of a cupola are caused by the combustion of the CO, which, rising above the charging hole at a high temperature meets the air admitted at that aperture, and at once burns into CO_2 in the upper part of the cupola.

The gases thus formed, along with the inert nitrogen driven into the cupola by the blast, leave the melting zone of the furnace at a very high temperature, and except in so far as they communicate their heat to the coke and iron further up the stack, carry with them a large amount of heat. Attempts have been made to utilize this heat. Some of the unconsumed gases have been conducted back to the tuyeres and again driven into the furnace. The value of this proceeding depends upon the quantity of CO present and as this is continually fluctuating throughout the course of the operation of melting, while at the same time large quantities of inert

gases are driven into the cupola, which would abstract heat on their passage through the combustion zone, it is very probable that the amount of heat generated by the small quantity of CO admitted, is more than counterbalanced by the abstraction of heat made by the carbon dioxide and the nitrogen.

A further loss of heat is occasioned by radiation, the heat passing through the lining and shell of the furnace, and escaping into the air. It has been sought to conserve this heat by water jacketing the cupola, and producing steam, which could be used for warming the foundry, for heating drying stokes, or for engine purposes, but here the non-continuity of the process is a difficulty, as the steam is only available when the cupola is at work.

The formation of the slag is also a cause of the loss of some heat. Under ordinary working, slag is formed at the rate of from 40 to 80 lbs. per ton of melted iron, and as this slag leaves the furnace at a temperature of some 1300° C., and no use having yet been discovered to which it may be put, there is here a not inconsiderable loss of heat.

As has been previously indicated, the presence of moisture in the coke causes a sensible loss of heat units. It is practically impossible to obtain coke devoid of moisture, which may range from 2 per cent to 6 per cent of the total composition of the fuel. To simply evaporate this would abstract heat from the furnace, but in addition the steam, coming in contact with the highly heated coke, actually decomposes, as the following equation shows: $C + H_2O = CO + 2H$. But this reaction only takes place in the presence of great heat, a large portion of which, amounting to 70,800 British thermal units per lb. of water, is absorbed in bringing about the reaction.

A suggestion has been made that to dry the blast before its entry into the furnace would effect an improvement in the melting capacity of the cupola, but it is problematical whether the possible saving in this respect would not be outdone by the extra cost entailed by the working of a drying plant of the size required. It may be interesting to note that in connection with American blast furnace practice, the dry blast has been tried and it is stated that the improvement in melting represents a gain of 15 per cent. Even if this is accomplished in the blast furnace, it is obvious that such a result could not be attained in an intermittently worked cupola, and the cost of producing the blast would be higher.

As an instrument for the melting of iron, the cupola is unrivalled from the point of view of rapidity, efficiency and cheapness, both as regards fuel and maintenance, and it lends itself to intermittent working according to the requirements of the foundry. Unfortunately, however, it possesses serious disadvantages in that it will not allow of any control being exercised in the composition of the material melted, or in the rate of melting, or the constancy of the temperature of the metal melted. In many classes of foundries absolute control of the temperature and the composition of the metal is not a necessity, and consequently in these cases the cupola fulfils every requirement. In higher classes of work these defects in the cupola method of melting form a very serious disadvantage. Other methods of melting are at the disposal of the foundry, and may be summarized as follows—

(*a*) Crucible furnaces ;

(*b*) Reverbatory and regenerative furnaces ;

(*c*) A combined cupola and electric furnace, commonly known as the " duplex " furnace.

The melting of iron in crucibles is only possible when

small quantities are required at a time. This is due to the limited size and capacity of crucibles, which for the most economical working rarely exceeds about 300 lbs. By installing batteries of crucibles it is of course possible to melt large quantities, but this is very seldom done owing to prohibitive costs. The life of a crucible is short, and the fuel cost for crucible melting is extremely high. The type of crucible furnace most frequently used for melting cast iron is some form of coke-fired furnace, either as a self-contained unit or in the form of a hole in the floor, as in the case of brass and steel crucible holes. Gas-fired crucible furnaces of the self-contained type can be satisfactorily used, but are found to be extremely high in fuel costs when melting pig iron and scrap from the cold. The cost of crucible melting could be considerably lessened by running the crucible as an adjunct to the cupola, making it the second stage of a double process in which the molten metal is taken from the cupola and kept at the required temperature, while the composition of the metal is being adjusted to suit particular requirements. This would obviously effect considerable economy in the fuel used by the crucible furnace. It need not be emphasized that the crucible method of melting allows greater possibilities of control of temperature and composition, and it is a well-established fact that the mechanical properties of crucible melted metal are higher than those of metal of the same composition melted in the cupola.

A simple reverberatory furnace consists of a hearth, hollowed out in the form of a saucer, roofed in, and connected on the one side over a bridge direct to a fire box, and on the other side to a chimney flue or stack.

A diagrammatic illustration of this is given in Fig. 4. The flames and gases produced by the combustion of

coal in the fire box pass over the metal lying in the hearth, and are usually deflected by shaping the roof in the manner shown in the sketch, in order to bring the flames into direct contact with the metal. The pig iron is charged on to the hearth, previously made of sand or other refractory material through charging doors provided on one side of the furnace, and when melted is tapped out through a tap hole on the opposite side of the furnace. In effect, the reverberatory furnace

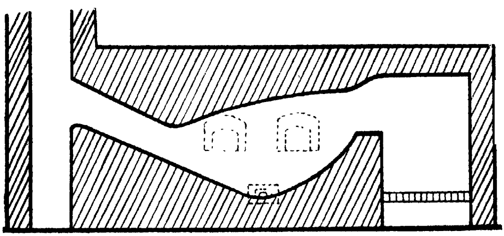

FIG. 4.

DIAGRAM ILLUSTRATING REVERBERATORY FURNACE

resolves itself into an extended application of the crucible furnace capable of dealing with large quantities of metal. The disadvantages of this type of furnace are twofold. In the first place, a considerable reduction of the carbon content of the metal takes place owing to the direct contact with the flame. This can to some extent be prevented by using large quantities of metal, and covering the same with a coating of slag, and, further, recarburizing can always be effected by the addition of coke or other carbonaceous matter at a suitable stage of the melting. In the second place, in such furnaces the running cost and the upkeep are extremely heavy, and to this must also be coupled the

fact that furnaces of such dimensions as are required cannot be run intermittently.

The regenerative furnace may be considered as a modified type of the reverberatory furnace, in which the hot waste gases, which would otherwise pass directly into the chimney, are carried through passages of chequer work, which, with the provision of suitable reversing devices, allow of the preheating of the air for the combustion of the fuel. By this process a considerable economy in heat units is effected. It is also common in this latter type to burn the fuel in separate gas producers, and to arrange for the gas thus generated to be burnt with the preheated air in the furnace body. Both these types of furnace find a limited use in the melting of iron for extremely large castings, and they are also used in the manufacture of iron for malleable castings.

With the development of the electric furnace during recent years the use of this furnace in conjunction with the cupola has been adopted somewhat extensively in America. Owing to the very high cost of electric energy, the direct melting of pig iron and scrap in the electric furnace is generally uneconomical. The use, however, of an electric furnace as auxiliary to the cupola, in which the metal previously melted in the cupola is transferred to the electric furnace, eliminates to a large extent the expensive initial melting period of the electric furnace, and affords an unparalleled means of controlling both the temperature and the composition of the metal. The atmosphere inside the electric furnace can be maintained either oxydizing or reducing at will, which allows of the manipulaion of the carbon content to very fine limits ; and by using a slag covering to the metal, refining in the shape of dephosphorizing and desulphurizing can be carried to any extent required.

CHAPTER VI

MOULDING—PRINCIPLES AND MATERIALS

THE proper control of the cupola in an ordinary foundry, and of the furnaces, crucible or reverberatory, in special work, is necessary for the production of metal which shall satisfy the special requirements of the engineer as mentioned in Chapter II. Of equal importance is the work of the moulder in the preparation of the moulds into which the metal has to be poured. Moulding is essentially an art, but the appreciation of the artistic side of moulding is unfortunately lacking in this country, and from this standpoint British moulding compares unfavourably with that of the nations of more artistic temperament, Italy, France and Belgium. The making of the mould for an intricate casting is a work of art, and it is essential that a really good moulder should possess a sound knowledge of all the materials in which he works and of the properties of the metal which has to be cast, as well as initiative, adaptability, manual dexterity, delicacy of touch, and in many instances a fair amount of physical strength.

The making of a mould for casting is generally performed by means of a pattern, which is in most cases made of wood, but which may be of metal or plaster. This pattern, as made by the pattern maker, is usually made in separate sections to facilitate the making of the mould by enabling the moulder to withdraw it from the mould when made, and also to avoid the risk or possibility of damaging the mould during this removal. In the making of the pattern, allowance has to be

made for the contraction on cooling of the hot metal poured into the mould, and consequently the pattern is always a little larger than the finished article. Experience has shown that ordinarily contraction must be allowed for at the rate of about $\frac{1}{8}$ in. to the foot, and in order to enable the pattern-maker to work directly from the ordinary measurements, special rules are made for the use of this trade in which this allowance is made so that a pattern-maker's rule apparently 1 ft. in length and divided similarly to an ordinary foot rule, is really 1 ft. + about $\frac{1}{8}$ in. in length.

The chief material in which the moulder works is sand, and speaking generally, the essential property of the moulder's sand should be its capability of bonding together, or retaining the shape into which it has been moulded, while at the same time it remains sufficiently porous to allow of the escape of the air in the mould, and of the gases generated by the action of the hot metal upon it and its binding constituents; and it must also be sufficiently refractory as to be able to withstand the very high temperatures to which it is subjected without risk of fusing, and be able to give a smooth and finished appearance to the surface of the casting.

Sand suitable for moulding purposes is found in many parts of the country: Lancashire, Nottingham (Mansfield), Yorkshire (Doncaster), Derbyshire, Cheshire, Shropshire, the Erith District, Falkirk and County Down being some of the districts in which sand for various types of moulding are worked.

Sand consists mainly of silica, which is known to the chemist as silicon dioxide (SiO_2), and which is found in a pure state as quartz or rock crystal, in grains in granite and crystalline rocks, and in other forms as

agates and flints. The grits and standstones are mainly composed of silica grains which are held together by various cementing materials, while in sands the grains are free. Along with the silica there is in moulding sands an admixture of some clayey matter which acts as a bonding material, and renders it possible to mould the sand into the form required, and also enables the sand to resist the pressure of the metal as it is poured into the mould. Oxide of iron, in the ferrous state, lime and magnesia are found in varying quantities in sand for moulding purposes, and as these substances may readily combine with silica under the conditions of casting, and form silicates which are comparatively easily fused, it is necessary that the percentage of these substances should be as low as possible in sands for moulding. The size and shape of the grains composing the sand are also of importance, as it is obvious that a sand consisting of round grains of equal size cannot form as strong a mould as a sand consisting of irregular grains which can overlap and interlock.

For the making of moulds of differing sizes sand of various qualities is required. As it comes from the sand pit, the sand is not in proper condition for the moulder's purpose, as it may contain stones, patches of clay, and other material impairing its value. It is therefore riddled and then milled. In the olden days it was well trampled and turned until it had been thoroughly mixed, and each grain of silica covered with a fine coating of clay, which is the chief aim of the procedure. This is now accomplished by grinding the sand in a sand mill similar to the mortar mill in common use. In one improved type of mill there is an overhead drive, the weight of the pan being carried on conical rollers, the pan also being driven by spur gearing in lieu of the ordinary bevel gear, which is thus not affected by any

wear which may occur on the rollers. The grinding wheels are so arranged that they can be set either on the bottom of the pan or at varying distances from it, thus producing different grades of sand according to the height and pressure of the wheels on rolling on the sand. In usual practice new sand, old sand and a quantity of coal dust or powdered charcoal are ground together. The latter is added for reasons which will be discussed later. The floor of a foundry is composed of a bed of sand suitable for the type of casting to be made, and of sufficient depth to provide a reservoir of sand for the moulds, and if necessary to allow of big castings being made in the floor.

Sand is used in almost all moulding processes, the exceptions to be dealt with later. According to its condition in the making of the mould, and in its finished condition in the mould before casting takes place, the different types of moulding receive their names. Moulds made in the ordinary damp sand without any drying previous to the metal being poured into them are said to be made in green sand, while castings made in moulds, which, first prepared in green sand, have been thoroughly dried before the metal is poured, are termed "dry sand castings." There are also large castings generally of circular or similar section to be made, for which the cost of making complete patterns would be prohibitive, and the moulds for these are usually built up with brick and covered with sand mixed with water into a stiff paste, so that it can be moulded by variously shaped boards or strickles rotating on an axis, or moving along guides into the shape required. This method goes by the name of "loam moulding."

If in the article to be cast it is required that there should be cavities or holes, that is, that the castings should not be solid, as in the case, to take a very simple

example, of an ordinary pipe, it is necessary that in the mould this cavity should be filled with material which will confine the metal into those channels which will, on the metal solidifying, give the required shape of article. These "inside moulds" are termed cores, and core making as a matter of fact is a special branch of the moulder's art. The question as to whether a mould should be made in green or dry sand is primarily a question of cost and finish, the amount of machining to be done on the finished casting, and the type of moulder available for the work.

The general principle in moulding is that the pattern of the article to be cast is embedded in the sand producing its shape in the moulding material, and then, the pattern having been removed, the cavity is filled with molten metal. All the appliances and methods of the foundry are focused to this end. The mould is generally made in a box or flask which may be built up in sections made to fit over each other and to fasten securely together for the purpose of confining and strengthening the sand mould (Fig. 5). Moulding boxes may be made either of wood or iron, but in ordinary practice metal boxes are commonly used, as they are capable of standing more severe treatment and do not warp as wooden boxes do. They are made of all sizes and of a variety of shapes, in section round, square, or rectangular, or a combination of all three. Most patterns may be moulded in two boxes, an upper and a lower box, often termed the cope and the drag, but in many instances it is necessary to have other boxes fitted intermediately between the cope and the drag to accommodate the pattern satisfactorily, and such an arrangement is known as a nest of boxes, the intermediate boxes being technically termed "mid parts."

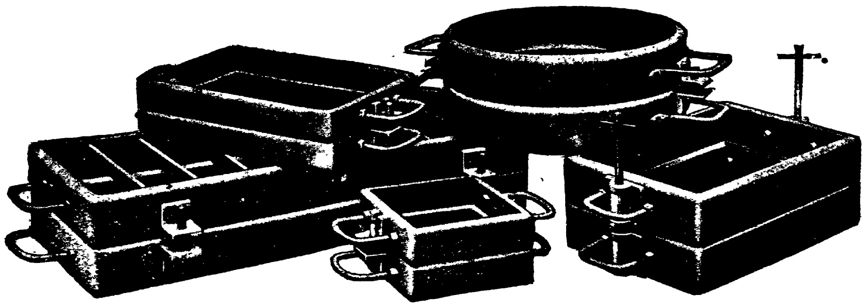

Fig. 5.

TYPES OF MOULDING BOXES

(The Blackfriars Foundry Requisite & Equipment Co., Ltd.)

In the construction of boxes cross-bars are introduced from one side of the box to the opposite side to assist in holding the sand. In drags, which may require lifting or moving when the pattern is made in them, the bars are formed with their flat side along the plane of the length of the box, while in the cope which may have to be lifted off the pattern and turned over, the bars are edgewise in the box, the flat side of the bar being almost the depth of the box with the inside edge narrower than the outside. This arrangement furnishes great support to the sand and enables it to withstand the extra handling necessary. Middle parts are made without bars but with a flange round the inside of the box. The edges of the boxes which have to be fitted are planed so that a true joint may be made. Unless this is done there is always danger of metal escaping and forming a fin on the casting or even running out of the mould altogether. Boxes have to be rigidly and accurately fastened together and this is ensured by providing each box with a series of lugs, the lower one carrying an upright pin and the upper one being drilled to slip over this pin easily but without any looseness or play. A cotter passing through the pin locks the two boxes together. Frequently boxes are fastened together by means of cramps, one end of which passes under the box and the other over the edge of the cope, the requisite firmness and rigidity being obtained by means of wooden or wrought iron wedges. Handles of some form have also to form part of the furnishing of the box, to enable it to be lifted or turned. These may be either straight projecting rods, or shaped pieces generally cast on to the sides of the box. Boxes which have to be lifted by the moulder are made as light as is consistent with rigidity, as even a comparatively small box when filled with sand is of considerable

weight, but in larger boxes which will require to be moved by mechanical means, the sides and parts are made thicker as the boxes come in for much more severe handling.

The procedure of moulding in its simplest form is as follows: Take, for example, the making of a solid round casting, the pattern of which is divided longitudinally along the centre, the two halves when together of course making the complete pattern. One-half of the pattern is placed on an iron or wooden plate, with its divided face downward, and the bottom box open side downwards is placed over it. Sand is gradually placed over the pattern, and rammed or pressed into shape with a tool, this process being continued till the box is filled. The other half of the pattern is treated similarly in the upper part of the box. These two half-moulds, having been turned over to allow of the extraction of the pattern, are now fitted together and tightly clamped or otherwise fastened. In the construction of the mould channels or passages have been made whereby the molten metal may enter and the air may leave the mould. The metal being now poured in through one channel, quickly fills the mould, expelling the air through the exit passage, and rises up this channel showing that the mould is full. In a little while the metal will have solidified, and the boxes are loosened from each other, the sand knocked away from the casting, and the extra pieces of metal which have solidified in the entry and exit channels are broken off. All necessary precautions having been taken and the work properly done, the resulting casting will be a perfect representation of the mould, and will be ready for the next process of manufacture or for use. If in place of a solid casting a hollow one is required, a similar procedure is followed, with the further process of fixing, when the pattern

giving the outside shape is removed from the mould, a sand mould or core, which completely fills the space to be left unoccupied by metal, being the shape and size of the inside of the article to be cast. After the cast, the core is at once broken up and removed from the inside of the casting.

CHAPTER VII

METHODS OF WORK—MOULDING TOOLS

HAVING obtained a general idea of the principles of moulding, it is now necessary to go further into the details of each operation and the reasons for any particular method of working.

It has been mentioned that various qualities of sand are used, and the first operation of moulding consists in placing round the pattern a mass of sand of the texture requisite to produce a sufficiently strong face on the inside of the mould to obviate the possibility of the inrush of the molten metal breaking down the face of the mould at any point. This special quality of sand goes by the name of facing sand, and of course consists of sand with a high bonding property. It may be mixed with a proportion of the floor sand, according to the strength of the particular mould face and the character of the finish required on the casting, and also according to the character of the new sand brought into use. The satisfactory face having been obtained round the pattern, in which the moulder is guided by his past experience, the remainder of the moulding box is filled up with the sand from the floor of the foundry.

The ramming of the mould is one of the special points in moulding practice. Insufficient ramming means that soft places will be left in the mould, resulting in all probability in the washing out of such soft places when the molten metal flows past them, or to their sinking as a result of compression due to the weight of the metal lying against them, forming bulges and scabs on the casting; but on the other hand, any part of the mould which has been over-rammed, or rammed too hard,

will have become almost non-porous, and this will prevent the escape through the sand of the gases and steam generated by the action of the heat on the sand and its binding materials and cause faulty castings, due to entrapped gases forming blowholes and like defects. Boxes are rammed up by means of tools technically described as "rammers," and these are of various sizes and shapes. For small work, and in ramming the sand round the pattern, tapering, blunt-ended, or rounded rammers are used, the length of the handle depending upon the portion of the mould to be rammed, and the amount of ramming required to be done, while in ramming the sand for the filling of the box or for preparing the sand bed in larger moulds, round or rectangular rammers are used. Upon the type of work to be done depends the weight of the rammer used, and the quality of the work performed, that is, the perfect binding of the sand grains, and the certainty that porosity has not been destroyed, is judged by the moulder in the feel of the ramming, a knowledge that only comes of long practice and experience. The amount of energy expended by the moulder in the ramming of large moulds is very great, and by the introduction of pneumatic rammers this work can be very much reduced, but these tools are open to the objection that the moulder cannot to the same degree "sense" the condition of the sand as he rams. For this reason it is often preferable that the facing sand be rammed by hand, even if the rest of the mould be rammed by the tool. In recent years with the introduction of machines for moulding, the actual ramming of moulds by hand labour has been largely eliminated, and (especially in the United States) is performed by mechanical jarring or pressing methods. This will be further dealt with in the chapter on machine moulding.

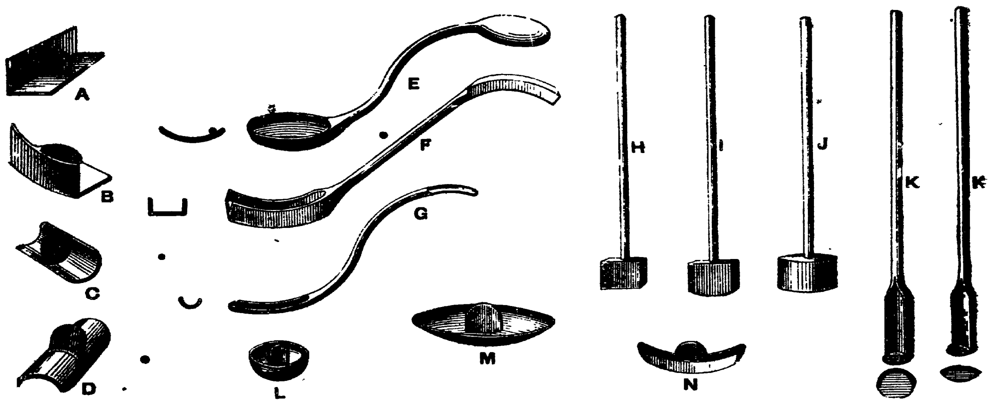

Fig. 6.

MOULDER'S TOOLS, SLEAKERS, ETC.

It frequently happens in the filling of the boxes that there are large quantities of sand between the pattern and the sides of the box. If no means of supporting this sand other than its inherent binding properties after ramming were available, there would be great risk that when the finished mould had to be lifted or moved, such masses of sand would break loose by their own weight not having sufficient cohesion to hold together. To prevent such disaster properly supported rods and bars of iron, technically termed "gaggers," are introduced into those parts of the mould requiring support, and the fixing of these calls for thought and ingenuity. It will be readily perceived that many possible castings require ingenious devices for holding, strengthening, and maintaining in position intricate overhanging parts, the success or otherwise in dealing with which depends entirely on the individuality of the moulder, and readiness in dealing with problems of this type is one of the attributes of a skilful moulder.

In many moulds there are often flanges or projecting portions in the interior, which without good support would be in danger of being broken off by the incoming metal. The necessary support in such cases is given by strengthening the projecting parts by sprigs, which are nails from 3 to 6 ins. in length, pushed from the front of the projection into the mass of sand behind, the holes then being mended up.

As mentioned in the previous chapter coke or other similar material is ground up with the sand in the mill. This is done so that the particles of sand may not come in actual contact, and so to obviate the risk of the intense heat of the molten metal fluxing the grains together and forming a glass-like slag which might adhere to the outer surface of the metal and cause it to become a spoiled casting. It will be readily appreciated that

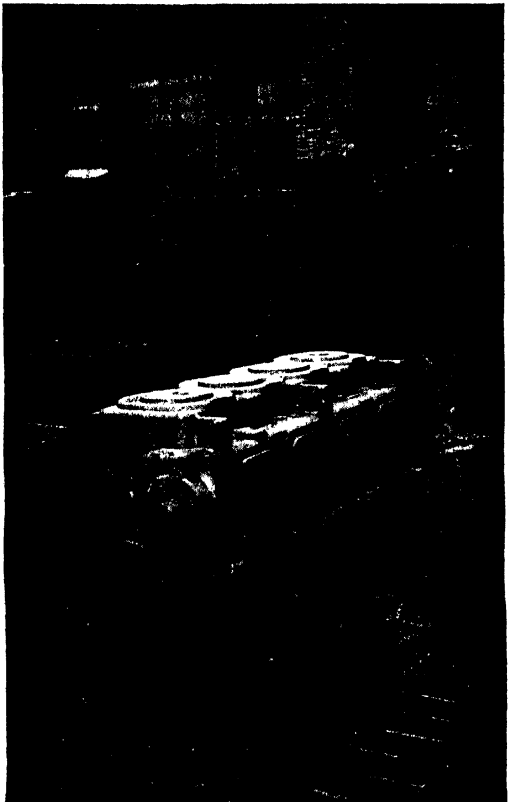

Fig. 7.

PATTERN FOR GAS ENGINE CYLINDER

(The Campbell Gas Engine Co., Ltd.)

when the metal is poured into the mould on its completion, the action of the tremendous heat upon the moisture in the sand, and on the carbonaceous substances which are mixed with the sand will produce large volumes of gases of various descriptions. Unless the gases thus formed are enabled to escape in some other direction as rapidly as they are formed, they will endeavour to escape through the metal itself, and in all probability bubbles of these gases will be entrapped in the cooling metal and form blowholes in it, even if the force of these escaping gases did not violently expel the metal from the mould to the great danger of all concerned.

Therefore the mould being rammed up, it has to be made certain that sufficient channels of escape are left for these gases to make their way through the sand, and the more rapidly these are conducted away, the greater likelihood of a successful ending to the operation. These channels of escape are termed, in foundry language, "vents," and are made in the sand by means of venting tools, which are simply wires or thin bars of iron of varying thickness, which are thrust into the sand almost to the face of the pattern. On withdrawal, long holes or channels are left in the sand, by means of which these various gases are enabled to make their escape.

In the case of large castings made in the floor of the foundry, a bed of coke is frequently laid under the mould so that the gases generated at the bottom may have an easy way of escape. A sufficient thickness of sand to support the mould is laid on the top of the coke and rammed, the venting rod being driven through this into the coke, the holes being separately stopped at the upper end by a wad of sand, preventing any metal entering the vent holes, but

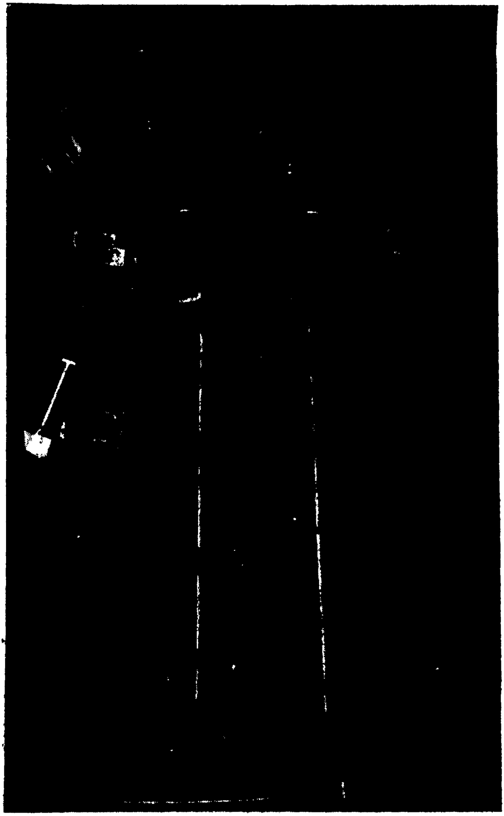

FIG. 8.

PIT DUG AND BED PREPARED

(The Campbell Gas Engine Co., Ltd.)

being at the same time sufficiently porous as to allow the gases to penetrate to the coke bed, from which they are conducted away by means of pipes the lower end of which are in touch with the bed of coke.

The mould being so far made, it is necessary to remove the pattern. The part which has been rammed is now turned over by the moulder, and the plate removed; so that the flat side of the half-pattern is visible. The drawing of this pattern is a procedure needing great care, and various means are adopted to perform the operation. In small work a thin bar may be fitted into a hole in the flat surface of the pattern, while the heavier patterns are arranged with hooks or lifters of various designs so that they may be lifted, often by means of the crane. Judicious tapping of the pattern sufficiently detaches it from the sand, when it is most carefully and steadily drawn out of the mould. It will be obvious that any violent or irregular movement in the tapping or withdrawal will prejudicially affect the mould, causing it either to be bigger than the pattern in the direction of the force of the blow, or drawing away the sand from the face of the mould, necessitating mending. It will also be obvious that such ramming as would cause the sand so to adhere to the pattern that tapping would not cause separation will be detrimental to the quality of the finished mould. There are, however, frequent occasions when, in spite of the care taken, certain portions of the mould are not in perfect condition when the pattern is withdrawn, and the moulder has to make these portions good. In the doing of this he uses a variety of tools, which are of special shape and size to suit different forms and sizes of moulds. Trowels, which may be rectangular, tapered, or heart-shaped, and smoothing tools termed "sleekers," of which there is a great variety, are the chief tools

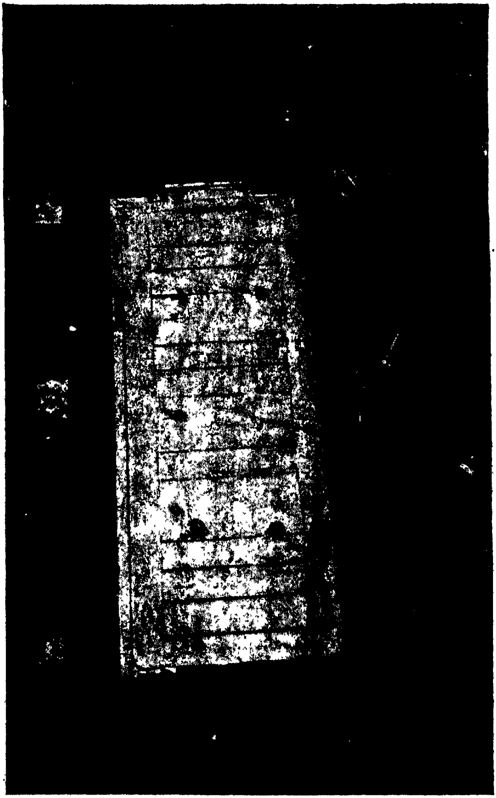

Fig. 9.
PATTERN IN POSITION
(The Campbell Gas Engine Co., Ltd.)

used. An idea of these various tools is given in Fig. 6. Sleekers are used to finish off the surface of a mould when trowels could not be used, as on curved or narrow sections.

The surface of the mould when perfectly made and repaired is now under ordinary conditions covered with a coating of blacking, which consists of a preparation of charcoal, plumbago, gas carbon, oil carbon, coke or coal dust, and this is either applied as a fine powder to adhere to the damp surface of the mould, or as a liquid mixed with adhesives such as clay, gums, or molasses. The object in view in using blacking is to prevent the molten metal coming into actual contact with the grains of sand, and possibly fusing them together, and thus to ensure the making of castings with a good "skin" or surface. The blacking must be composed of material which possesses a high degree of infusibility and is at the same time sufficiently porous as not to affect the porosity of the sand in the mould, and for these reasons it is made of some form of carbon as above stated. The blacked mould is finally sleeked so that the blacking may lie evenly on the surface and be of the requisite thickness in all parts.

Should the mould be now required for a dry sand casting it has in addition to be dried in an oven, and in this operation the moisture is driven out from the sand leaving it much more porous. A stronger sand is in general used for dry sand casting than for green, and the mould will bear closer ramming and require less venting because of the greater porosity of the dried mould. It will be appreciated that the drying of a mould adds to the cost, and necessitates the removal of the mould into an oven. So the practice of "skin drying" is now very largely adopted. This process, which is cheaper than drying altogether, and which

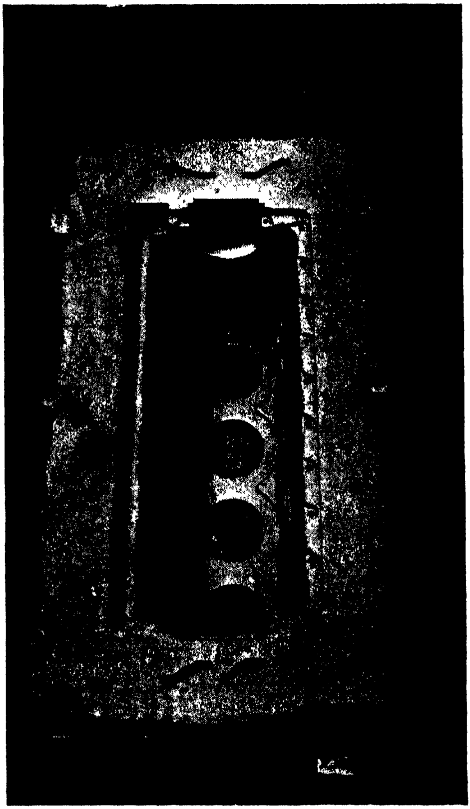

FIG. 10.

PATTERN REMOVED

(The Campbell Gas Engine Co., Ltd.)

can generally be done without removing the mould, consists in applying heat to the surface of the mould, and drying that, while the parts of the mould remote from the surface are left in the green state. The heat may be applied by means of oil burners or jets of producer gas, and moulds thus treated give equally good results in the majority of cases as if they had been entirely dried.

The mould giving the external shape and dimensions required having been prepared, the cores necessary for the internal shape and size are now fixed. Wherever it is possible in the making of a pattern, a piece of wood representing an extended portion of the section of the core required to occupy the internal cavity is fastened in position on the outside of the pattern and this when imprinted in the sand affords a fixing place upon which the core can rest in correct position. These projecting sections are named "prints," from the fact that they imprint in the mould the correct position of the core, and are illustrated in Fig. 7. To ensure the correct fixing of the cores, it is frequently necessary to place the upper part of the box upon the lower, and then remove it for examination. Adhesion between the two faces of sand is prevented by a thin layer of sharp sand, devoid of bonding properties, which is technically called "parting sand." The cores, having been accurately placed in position, have to be firmly fixed so that during the flowing in of the metal, no movement is possible, as otherwise the internal dimensions of the casting would be different from what was required, and the casting would be defective. It will be readily appreciated that in the case of a long core, a pipe core for example, supported at both ends on prints, the pressure of the heavy molten metal would float the yielding centre portion of the comparatively

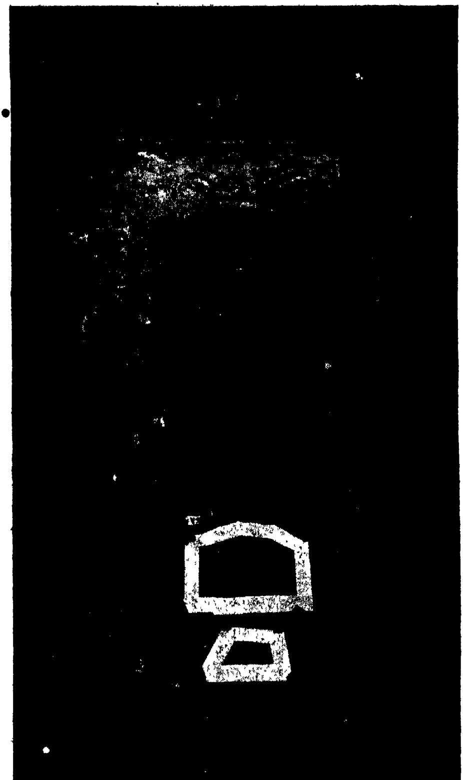

Fig. 11.
CORES IN POSITION
(The Campbell Gas Engine Co., Ltd.)

light core upwards towards the top of the mould, giving a thick section of metal at the bottom of the mould, and a correspondingly thin one at the top. To prevent this occurrence, small pieces of metal called "chaplets," of various forms and of the precise thickness required, are fixed between the core and the mould where any movement may be expected. These chaplets are used to ensure that the core keeps its correct position in relation to the rest of the mould, and the fixing of these calls for thought and adaptability on the part of the moulder, and for great care in manipulation. It is essential that they should be placed where they are of maximum value for the purpose, and in such a manner that when the pressure is applied the chaplets are not forced into the surface of the mould, or break the skin of the core. It is often necessary, where great pressure is anticipated, to reinforce the chaplet by a rod passing through the outer part of the upper box to the chaplet, and fixing the outer end of the same firmly. It is particularly desirable that the chaplets should be free from moisture and rust, as otherwise the presence of these would, by the generation of gases under the extreme heat, tend to produce blowholes and porosities, or to prevent the complete welding of the chaplet into the casting. Cores having been accurately placed and securely fixed, the upper box being in position above the lower, the mould may be considered as almost completed and ready for casting. It will be easily understood, however, that any separative movement of the boxes during the pouring of the metal into the mould would be disastrous to the casting itself, and would probably cause injury to the men near the mould. The boxes consequently have to be securely fastened together. How great the pressure tending to cause separation is in any particular mould can be calculated.

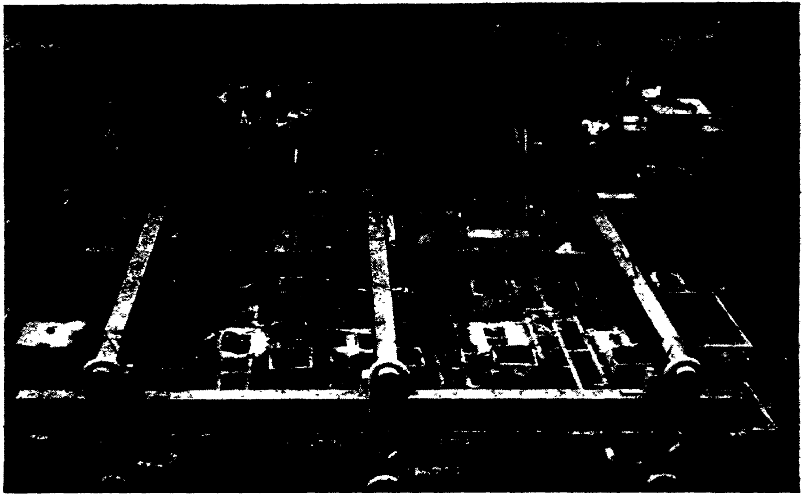

Fig. 12.
THE COMPLETED MOULD
(The Campbell Gas Engine Co., Ltd.)

Fluid pressure is proportioned to the height and density of the liquid, and is easily expressed in lbs. per sq. in. For example, if the height of the pouring basin above the top of the casting in the cope be 8 ins., and the upper surface of the casting has an area of 2 sq. ft., the pressure of the molten metal on the cope would be $8 \times (2 \times 144) \times \cdot 261$ lbs. (1 cu. in. of iron weighing a little over $\frac{1}{4}$ lb.), which would give an upward pressure of nearly $5\frac{1}{4}$ cwts. on the cope. Consequently the cope will require to be weighted down to that extent (including its own weight), to prevent any lifting during casting. Frequently weights are distributed on the top of the mould to effect this, but a better way is to clamp the boxes rigidly together. In large castings made in the floor, the upper portion of the mould having bars or beams placed across it, is securely held by tie rods and links which connect the bars or beams across the top to similar beams or grids which have been previously fixed under the bed of the casting. The series of photographs Figs. 7 to 13, kindly supplied by Messrs. The Campbell Gas Engine Co., Halifax, show in a very interesting manner the chief operations and methods employed in the production of a monobloc cylinder casting for a vertical gas engine made in the floor of the foundry. Fig. 7 represents the pattern and the numerous prints may be noticed. Fig. 8 shows the pit dug and the bed prepared. Fig. 9, the pattern inverted in position on the bed. Fig. 10, the pattern rammed up and withdrawn and gates prepared. Fig. 11, the cores placed in position and showing the venting of each core by means of coke. Fig. 12, the mould ready for pouring. The method of clamping. Fig. 13, the finished casting.

In loam moulding, though the end in view is precisely the same, the methods adopted in the construction

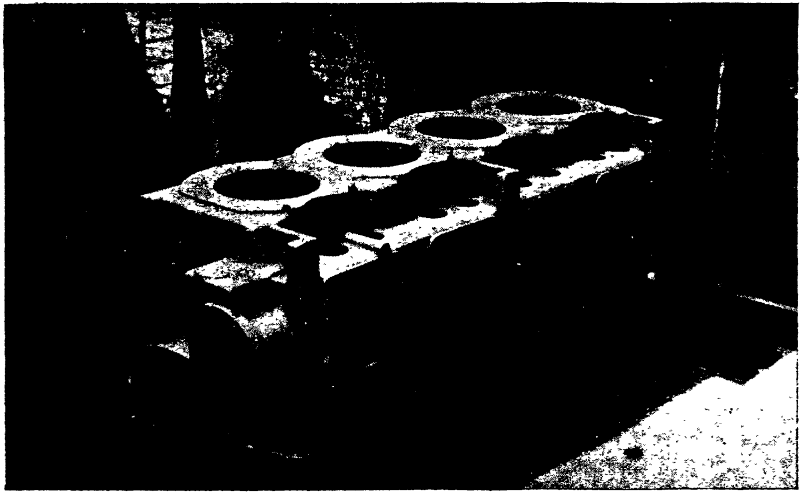

Fig. 13.

THE FINISHED CASTING

(The Campbell Gas Engine Co., Ltd.)

of the mould differ from those just described in several important respects. As mentioned in Chapter VI, this method is generally applied to those articles of circular section and large size, the making of wooden patterns for which would greatly increase the cost, and which may not be required in large numbers. Being large, the mould and core are usually built of brick upon a foundation plate of sufficient strength to carry the whole mould when completed, and strengthened and supported by ties or iron plates. The brickwork is formed roughly in the shape of the mould and core desired, and venting is obtained by allowing joints of from ½ in. to 1 in. filled in with loam which is used in lieu of mortar as in ordinary building. This being completed the whole is daubed over with coating loam and fashioned to shape by means of a sweep, which is a board cut to the required shape, revolving on a vertical spindle fixed in the centre of the mould. being finally completed with finishing loam, which is a loam of smoother consistency than that used for the rough coating of the mould. Both core and mould are now well dried, carefully fitted into position. and the mould closed ready for the pouring of the metal. Allowance for contraction during the cooling of the metal has to be made, otherwise, were the core made too rigid and unyielding, great risk of the metal cracking because of the stress thus placed upon it would be run. A number of loam bricks are therefore built into the structure of the core along with the ordinary bricks, and these allow of its yielding to the pressure exerted upon it by the contracting casting. It is also a wise precaution to break up the core as soon as possible after the casting.

CHAPTER VIII

MOULDING (*contd.*)—THE COMPLETION OF THE PROCESS

DURING the making of a mould as so far described no account has been taken of the means adopted for filling the mould with metal. This however is one of the most important points in the whole process, and many castings have been spoiled by insufficient attention being paid to this part of the work. Coincidently with the making of the mould as already indicated the moulder must decide the position, the shape, and the size of the channels by which the molten metal will enter the mould, and proceed with the making of these channels as his work progresses. Horizontal passages made to admit the metal are termed ingates or runners, while downward passages are called downgates, and the metal is first poured into a basin hollowed in the sand and termed a runner basin. Frequently the runner basin has to be formed on the top of the cope or upper box so that there may be a sufficient head of metal to completely fill the mould which may reach almost to the top of the cope. These channels must be arranged so that the metal may enter the mould as quietly, and yet in many cases, as quickly as possible, and in such a fashion that the risk of breaking down the sides of the mould is reduced to a minimum. It will be evident that if the metal enters the mould so slowly or at such a position that thin sections have time to solidify before the mould is full, or that the metal solidifies before completely filling any section, or if dirt is carried into the mould by the rush of the metal and becomes embedded in the casting, such castings will be wasters. And as the metal solidifies from the outside inwards, if

no arrangement is made to continue feeding metal into the interior of a thick section after the outside may have solidified, there is the probability, metal shrinking on solidification, of there being a spongy mass of metal of no strength in that particular section, or even a hole in the centre of that thicker portion of the casting. These points have to be considered, and such dispositions made as will ensure the soundness of a casting. That the metal may enter quietly, it is admitted into the mould under the following conditions. On being poured into the runner basin the metal overflows on one side into the downgate, falling into a smaller basin out of which it flows along the ingate into the mould. If it enters the mould at the upper portion the arrangement is termed top gating, but if there should be any risk that some part of the mould might possibly be broken by the impact of the molten metal on entering, the downgate is made longer and the metal passes into the mould at its lower end. This is known as bottom gating, and the metal rises in the mould till it is completely filled.

In the case of very deep castings a combination of the two methods is sometimes adopted, the metal entering at the lower gate forming a cushion for the top metal to fall on, and the falling metal preventing any solidification till the mould is completely filled. In making castings of thin section, the metal is often introduced into the mould by a series of runners termed a spray or sprue, extending possibly the whole length of the mould to minimize the risk of the metal becoming solid before reaching the extreme end of the mould if fed by only one runner. There are occasions when, owing to the shape of the article required, e.g. a cog-wheel, the metal cannot be introduced from the side, and in these cases it must be run in to the centre of

the mould. To effect this, the ingates instead of being straight as is usually the case are curved and of tapering form, the wider end joining with the downgate and the narrow end entering the mould. By this means the metal can be run into the mould either from its upper or lower sides. Such curved ingates are named "horn gates," and the tapering form of the pattern forming the gate allows of its easy withdrawal from the mould.

Rising from the top of the mould are channels somewhat similar to the gates, which act as outlets for the air, which indicate when the mould is full, and which allow of the floating out of any dirt which might be in the metal. A basin similar to that of a runner basin is generally formed at the top of such channel or riser as it is termed. The entry of metal into the riser basin is the sign to stop pouring. In large castings, or above any thick section, it is often necessary to arrange for feeding gates or heads to continue the supply of molten metal to the casting as the metal shrinks on solidifying. The narrowed entrance to the casting is kept open by a rod which is worked upward and downward so long as the metal remains molten.

The mould having been filled and the metal solidified, it is now necessary to break out the mould and take out the casting. In the case of small work this may be done in a very short time after casting, but with larger castings some time must elapse before the mould can be touched. But this having been done and the runner gates, risers and feed heads having been broken off, the casting is passed along to the fettler. His business is to clean off from the metal all the sand which may have adhered to it either from the mould or the core, and to take off all projecting pieces of metal in the

form of runner and riser ends or of fins which are not in the original design of the casting, and to render it presentable as a finished casting for the work which it will have to perform. Various means are adopted for the removal of sand from castings. Frequently it is done by means of a rattler, which is merely a revolving barrel into which the castings are packed so that while they are free to rub against each other, excessive jolting is avoided. The shaking and rubbing loosens and dislodges the sand, which falls out of the barrel, and it is an apparently singular fact that cast iron castings which have undergone this treatment are stronger than they were when put into the machine. Probably this is brought about by the vibration to which they have been subjected releasing some of the stresses which have been set up among the crystals during the period of solidification and contraction, and by thus enabling them to adjust themselves to more normal conditions produce a stronger material. In some instances a wire brush may be all that is required to remove the sand, while in some shops the sand blast is used for the purpose. This consists in driving a stream of fine particles of sand against the casting by means of a powerful blast of compressed air, the workman of course requiring protection from the flying sand, some form of helmet and respirator providing this. Another method sometimes adopted is that of pickling the castings in dilute acid, generally sulphuric, which loosens the sand from the metal, after which the castings are swilled with water. For the removal of all projections of metal not required on the casting, the fettler uses hammer and chisel, or a pneumatic chipper, or an emery wheel or file according to the class of casting he may be engaged upon, and having finished his work, the casting as such is completed.

A large number of the castings thus made have to have further operations in the form of machining or drilling performed on them in order to properly fit them for the special place they have to occupy in some machine, and for the particular work they have to perform, and these castings are now taken to the machine shop for this further treatment. But a considerable number are practically ready for the work they are designed to do when they leave the fettler's hands, and in these cases it is frequently necessary, before these articles are allowed to leave the foundry as perfectly finished castings, to treat them in some manner so that they may be preserved from rusting and at the same time to give them a good appearance. Various methods are employed for this purpose. Some castings are painted, frequently with red oxide paint, while others are exposed to the smoke from turpentine, and become covered with a fine deposit of carbon, while still others are dipped in hot tar, which, forming a film upon the outer surface, effectually preserves it from the action of the damp atmosphere. A further method introduced by Hans Renold consists in heating up the castings to a temperature of about 500° C. and then immersing them in linseed oil, which, forming a fine coating on the surface of the metal, acts as a rust preventative and gives a finely-finished appearance to the casting. This method was used largely during the war for rust-proofing bombs and hand grenades.

CHAPTER IX

FOUNDRY EQUIPMENT

In even a small foundry the amount of material which has to be handled is very considerable ; and frequently heavy weights in the form of boxes, moulds, castings and the like have to be lifted and conveyed from one part of the foundry to another. It will be obvious that in order to accomplish this removal and transport, mechanical means of high efficiency will be required if the work has to be economically and quickly performed. It therefore follows that cranes of various types are an essential feature in most foundries, and according to the size and weight of the castings produced at any foundry will depend the capacity of the cranes required, which may range from 1 to 50 tons. The kinds of crane in general use are the overhead travelling crane running on rails from one end of the foundry to the other, and traversing from side to side, so that service may be rendered when required in any part of the shop, and jib cranes of various designs, which are generally fixed to the side of the building, and serve an area commensurate with the length of the jib. These cranes may be manipulated by hand power, or may be driven by steam, hydraulic power, or electricity. In many foundries there are still to be seen the hand-worked crane for even heavy weights, but in modern practice the hand crane, being slow in movement and requiring the attention and energy of several men, is superseded by some form of mechanically driven crane, which besides being quicker in its movement, is under the absolute control of the driver. A foundry crane must be so designed that it will respond readily to all the

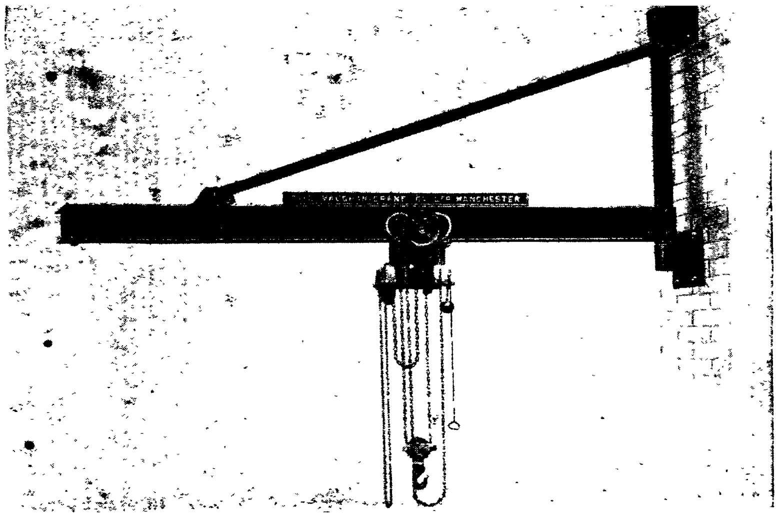

Fig. 14.

CRANE FIXED TO WALL

(The Vaughan Crane Co., Ltd.)

demands made upon it, and that its work can be performed with an entire absence of jerkiness. When it is considered that a portion of its work may consist in drawing large patterns out of moulds, or in carrying molten metal from the cupola to the moulds in various parts of the shop, the demand for absolute steadiness in working is a very important one; and so, generally speaking, the mechanically driven cranes are actuated by either hydraulic or electric power.

Foundries which may be engaged in producing nothing but small castings, may not find it necessary to have a crane service, but a service of tracks running on the beams of the building or on special runways may be sufficient to deal with all the weight that has to be handled, while in other instances a narrow gauge tramway running the length of the shop may be of great service. But in the majority of cases cranes are a vital necessity, and in many well-organized foundries all three methods of crane, runway and tramway are installed to secure that transport may be speedy and efficient. Slow-moving lifting and carrying appliances have frequently the effect of locking up moulding space and limiting output, while an efficient crane or transport service may render it possible for a smaller foundry to have an output equal to a larger one not so well served.

A very important part of the foundry equipment and management has reference to the chains by which the heavy articles to be dealt with are attached to the crane. These chains are affected oft-times by the varying temperatures to which they are subjected, and as a result of the repeated stresses to which the chains are subjected by continual use, the material of the chain becomes gradually fatigued, in which condition there is considerable risk of premature breaking. In the event of a chain breaking, the result may be a

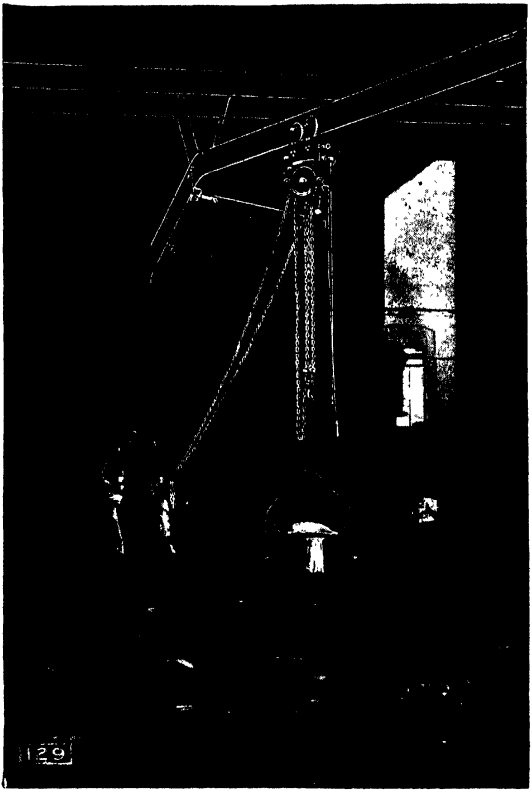

FIG. 15.

A RUNWAY

(The Vaughan Crane Co., Ltd.)

disaster, men being killed or injured, and much material damage may be done, so that it is absolutely essential in the interests of all concerned that chains should regularly be subjected to the most particular scrutiny, and in order that all strains may be released and the chain rendered safe, that proper normalizing[1] of all foundry chains should take place at stated intervals, preferably every few months.

Where it is possible to pass the chains round the mould or casting it is usual to sling the articles with chains only, but this can only be done in the case of equally balanced or comparatively small boxes and castings, and usually when it is required to deal with bigger moulds or irregular castings, a lifting beam is attached to the crane and the chains depend from this. A common form of chain has a large ring in the middle of the chain, by which it is attached to the crane hook, each half of such chain terminating with a hook. A heavy or unequally balanced mould which may require to be lifted is frequently built on a sufficiently large base plate, which, being attached to the lifting beam by chains, affords a ready means of moving the mould.

A very important service rendered by cranes in a large foundry is the carrying of the large quantities of molten metal required by large castings. The metal is tapped into ladles from the cupola, lifted by means of a sling, and carried overhead to the moulds. Smaller quantities may be conveyed by ladles fixed on carriages running on the tramway, or slung from the overhead runway, but very often the physical strength of the labourer is called into play in carrying shanks of metal

[1] Normalizing consists in subjecting the chain to a temperature slightly in excess of its upper critical point, after which it is allowed to cool down normally in the air.

by means of carrying tongs. A hand shank is often employed when only small amounts are required, and these are filled from a larger ladle brought into the foundry by one of the above means. These various types of shank and ladle are illustrated in Fig. 16.

The ladles are usually made of steel lined with refractory material such as sand or loam. It is imperative that the linings of all ladles should be bone dry before being used, as any moisture left in the lining will be converted into steam upon the pouring of the metal, such steam occupying many times the volume of the moisture, with its only way of escape through the metal which may be violently ejected under such conditions. Serious cases of burning have occurred through the use of damp ladles, and at the very least there is an unnecessary waste of material. Small ladles are poured by tilting with the tongs, but very large ladles which may carry amounts of metal from 10 cwts. upwards are generally tilted by means of a gear turned by a wheel, which ensures perfect control of the tilting movement. It will be plain that any occurrence which disturbs the steady pouring of the molten metal may be fraught with danger to all the workmen in the vicinity, and consequently the geared ladle is a necessity in foundries making large castings. The pouring spout of a ladle is shaped in such a manner that an even unbroken stream of metal can be delivered into a small shank or into the pouring basin of a mould with absolute accuracy.

In addition to the lifting and transporting appliances which in some form or other are common to all foundries. there are many other articles of equipment which are equally necessary. The tools which have previously been dealt with in the chapters on moulding are frequently the moulder's personal outfit, but there are

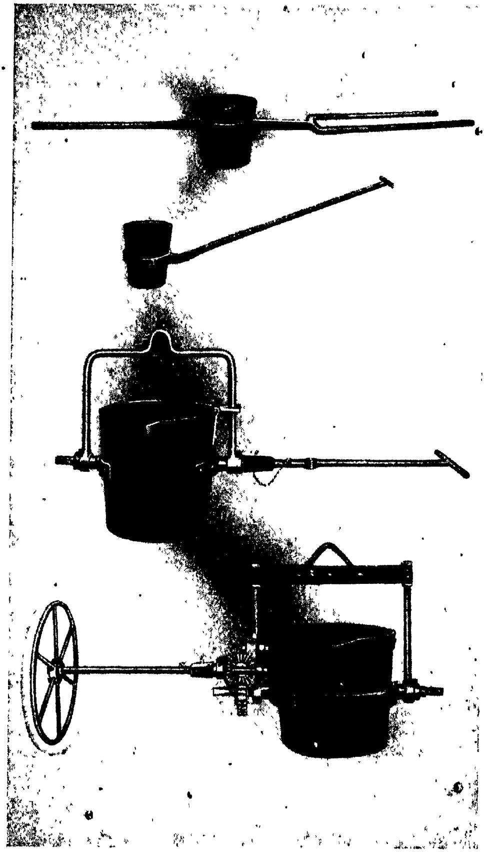

Fig. 16.

TYPES OF LADLES

many other tools which are more or less necessary and which are provided as part of the proper equipment of the foundry. Shovels, sieves, riddles, bellows, lamps, buckets, pots and pans for holding water, parting sand, oil, wet blacking and claywash, brushes of various sizes, cramps, hammers, crowbars, fire baskets, barrows, nails, chaplets and gaggers are in constant requisition in the foundry, and in a well-organized department a sufficient supply of these tools is distributed over the shop. It will be easily realized that the proper distribution of these articles in the places where they can be most conveniently obtained by the moulder requiring to use any of them may have a very important bearing upon the quality of the work produced, and upon the time necessary for the making of any particular mould and consequently upon the output of the foundry.

In large foundries, where great quantities of sand are regularly required, it is frequently found necessary, in addition to having a mill for grinding and preparing the sand to install a mechanical mixer which mixes and moistens the sand to any degree required for any particular operation, and some foundries have found it an advantage to have large bins where these various qualities of sand can be stored in readiness for the moulder.

The use of gas in drying stoves, core ovens, and for drying ladles and skin drying moulds has led to the installation in some shops of a gas producer plant. This consists of a furnace in which anthracite and other material, even to sawdust can be distilled, and into which a jet of steam is blown, which, decomposing and uniting in various ways with the products of distillation, give off inflammable gases such as carbon monoxide (CO), hydrogen (H_2), and marsh gas (CH_2), which are led into the ovens and stoves and sometimes to jets placed where required in the shop, and there consumed.

No foundry can be considered satisfactorily organized unless proper arrangements are made for the safe storing of patterns and boxes. In foundries which form an integral part of an engineering works producing a special type of machine, the foundry work becomes to some extent standardized and it may be a comparatively easy thing to store the necessary patterns and boxes which may be required from time to time; but in a jobbing foundry where work of all descriptions may be produced, storage of boxes and patterns becomes a much more important proposition. Boxes are generally stacked in the yard, those of similar size and shape being placed together, leaving gangways between the stacks so that any box required may be expeditiously obtained. This usually necessitates the fixing in the yard of some form of crane, which is also often used for loading up the finished castings on to truck or lorry. The patterns being of wood have to be stored under cover, and an efficient stores-keeper, part of whose duty would be the correct numbering, cataloguing and storing of these patterns in their position in rack or on shelf, is an asset to the productive working of a foundry.

One of the minor and still very important parts of foundry equipment deals with the preparation of the metal for the cupola. The pig iron as delivered at the foundry is too large in size for charging into the cupola, and in many instances the scrap which has to be used is in pieces which are too unwieldy to handle. Consequently means have to be adopted for reducing the size of this material so that its handling becomes comparatively easy. Frequently a sledge-hammer wielded by a muscular labourer is the means adopted to attain this end, but when heavy scrap is being used, mechanical means are employed. A heavy weight or tup is raised to some height above the material by a crane or pulley

block, which, falling when the catch holding it is released, crashes on to the pig or the scrap, effectually breaking it into pieces. Hydraulic pig breakers have also been installed in some large foundries.

In these days there is a tendency in the larger foundries, which appears to be a direct result of high labour costs, to adopt more extensive mechanical handling plant. The utility of conveyors, conveyor systems and similar mechanical devices will be readily conceived in large foundry plants and numbers of uses will suggest themselves. The adoption, more particularly in the larger American foundries, of conveyor systems of sand handling might be mentioned as an example. It is interesting to note on the authority of an English expert who recently visited some American foundries, that it is not economical to adopt systems of this nature when handling quantities of sand of less than 100 tons daily.

CHAPTER X

MACHINE MOULDING

In all other branches of the engineering world great advances in production have been made by the introduction of automatic or semi-automatic machinery, which is able to produce large quantities of articles of standard design and dimensions. Many examples of this development might be quoted, but it will suffice to refer to two only, which exist in the manufacture of screws and of the Ford motor-car, for which, every part having been designed of standard size and shape, machines which are almost perfectly automatic in their action, manufacture such parts with absolute precision and great rapidity. This method of manufacture results in a great reduction of working costs, and allows of articles being produced in immense numbers and at a much cheaper rate.

Until quite recently, the question of standardization in the foundry has to a great extent been neglected, but the demands made during the four years of war for rapid manufacture and delivery, and the high rate of wages obtaining as a result of war conditions, which will in all probability become fixed, have forced upon the foundryman the question of rapid production of articles of standard shape and size; and throughout the industry, great advances are being made in the direction of reducing to its minimum the man-power hitherto used in the foundry, and substituting machine for hand work wherever possible. Obviously, the introduction of machines or any other form of bulk production into any industry depends upon the number of

articles to be made. The initial cost of the machinery which may be introduced into the foundry, and the greater expense incurred in the making of the patterns and tackle for use in connection with these machines, demand that if the machines are to be used to advantage, the number of articles to be manufactured shall be large. This necessitates more extensive standardization of any article or piece of machinery than has hitherto been adopted, at any rate in this country.

It has been customary, when considering the question of foundry efficiency, to make comparison of the methods adopted here with those in use in the United States of America. The extensive adoption of mass production in that country even previous to the war may be said to be due largely to two fundamental factors, the first being the very great extent to which the principle of standardization has been accepted and acted upon throughout the whole range of their engineering practice, thus allowing of the most extensive introduction of labour-saving machinery and devices, and the second being the cosmopolitan character of the men who work in the foundries there. The importance of this factor does not seem to be appreciated at its full value by many who make these comparisons. Men of all nationalities, most of whom have gone to America with the fixed idea of financially improving their positions, work together in American foundries. The consequence is that, while they are willing to exert themselves far more than they otherwise would be prepared to do, they are also ready to adopt any practice which offers to them the possibility of increased income, and therefore the management of foundries in that country are less troubled by the reluctance on the part of the employee to adopt new ideas and methods than seems to be the case in this country.

Mr. A. O. Backert, lately the President of the American Foundrymen's Association, recently made a tour

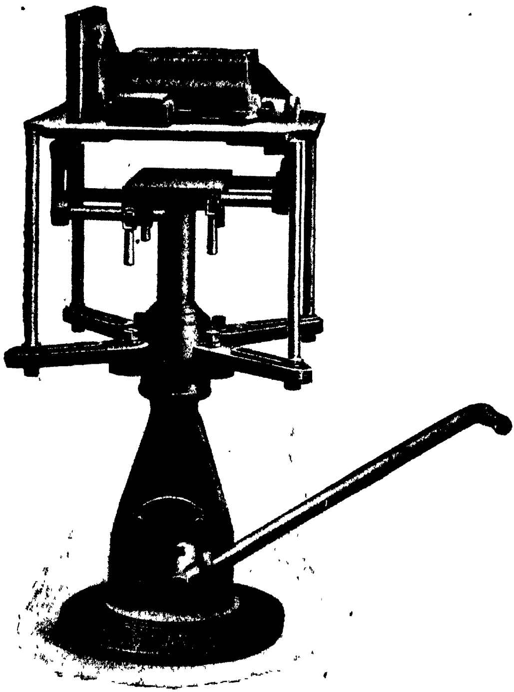

FIG. 17.
HAND RAM MOULDING MACHINE
(The Britannia Foundry Co.)

of inspection in Great Britain and France, and in his address to that Association delivered in Philadelphia he pointed out that the lack of standardization in

English practice was the great bar to the development of repetition work in this country. He instanced as a concrete example a large foundry specializing in the manufacture of domestic baths. He stated that this particular firm had accumulated great numbers of patterns for these articles in their stores, a fact directly traceable to the varying ideas and fancies of architects, who so modify the designs of similar domestic fittings in their various contracts as to necessitate this accumulation of patterns, which in its turn compels the casting of individual articles and bars the way to the introduction of mechanicalized mass production methods.

The methods employed in mass production have developed slowly from the early days of the foundry industry. Originating with the standardization of the ordinary methods of hand moulding, gradual development has taken place, and machines have been evolved which can successfully perform most of the operations of hand moulding, till now we regularly encounter machines which are capable of ramming, drawing of pattern, turning over, and even of closing moulds under the control of a semi-skilled labourer.

It is interesting to consider the devices and methods which have evolved in the practice of moulding designed to facilitate rapid and economical production of castings, some of which, however, can scarcely be classed under the head of machine moulding. One of these methods is the use of the snap flask, a moulding box generally made of hard wood, hinged at one corner and fastening with a snap or latch at the opposite corner. Generally small and light articles of no great depth are moulded in snap flasks, a procedure which is exactly similar to the making of a mould in an ordinary iron box. Snap flask moulding is done on the bench, and the mould having been made, it may be placed on the floor in

proper position for pouring, and the snap flask is then taken off to be used again in the making of a similar mould. This obviously will effect a great reduction in the number of boxes in use, and a saving of time in the fetching and returning of such boxes, and enable a workman to increase considerably the number of moulds he can produce. There is however the possibility of the mould thus made giving way when the metal is poured, and to obviate this such moulds when made are frequently placed in a trench prepared for them which is later filled up with sand round the moulds, or sand is piled up to the moulds to stiffen the sides and prevent a run out. Occasionally the moulds are held together by means of thin sheet metal placed round them. This method gives satisfactory results on small castings when no great number of each is required.

In the case of solid patterns having no flat surface which could rest upon a plate, it is necessary in order to hold the pattern to prepare a false top part, technically termed an "oddside" in which the pattern may be bedded and rest, while the bottom part of the mould is being made in the drag. The pattern is placed in a prepared cope and bedded exactly up to the joint. The drag is now placed in position, and the bottom part of the mould is rammed and vented. On turning over, the false top part is removed and another top part with runner and gates is made. The usual drawing and finishing of the mould is proceeded with, and the mould having been completed, the "oddside" may if required be used again for the same purpose. But as a green sand oddside is somewhat fragile, it is advisable, a number of castings of the same pattern being required, to prepare a dry sand oddside, which is often made with oil sand, and which will better withstand the necessary handling and turning. In the event of a greater number

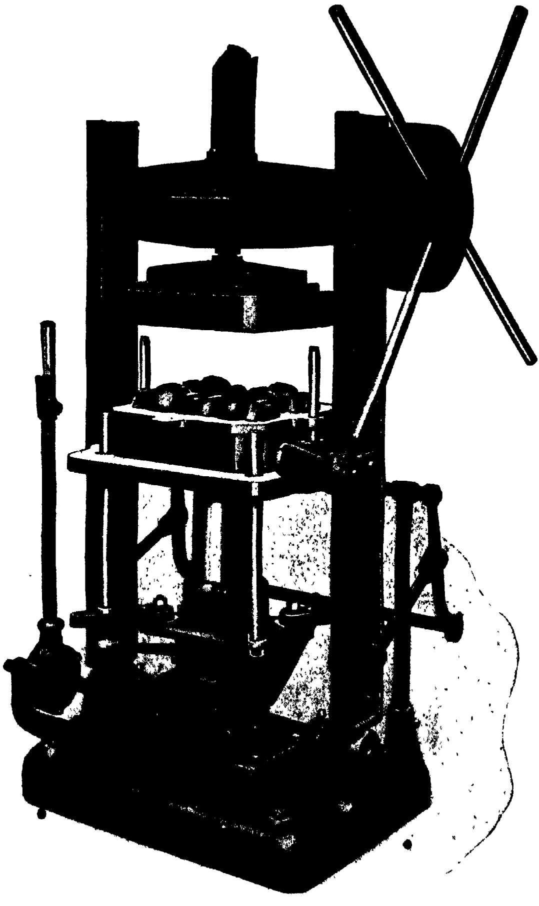

Fig. 18.
MOULDING MACHINE
(The Britannia Foundry Co.)

of castings being required, it is often found expedient to make a permanent oddside for this continued use, which is done by using plaster of Paris. The procedure in this case is precisely the same as already outlined up to the taking off of the green sand oddside after turning. The sand is then knocked out of the false top part which is again placed in position on the bottom box. The joint of the boxes is carefully stopped to prevent any leakage of plaster, which, of the consistency of thick cream, is now poured over the pattern which has been previously oiled to prevent sticking. On setting, the plaster oddside is lifted off, and can be used for the production of a large number of moulds. In repetition work of this type, it will be apparent that the use of a permanent oddside of this description will result in the saving of a considerable amount of time and labour.

An important step in the direction of rapid production, and probably the initial step in the introduction of machines for moulding, was made when the method of plate moulding was devised. Briefly this consists in fastening the half-patterns on opposite sides of a board or plate, with the flat faces exactly opposite to each other. This board becomes the turning-over board and is placed between the cope and the drag, the drag being uppermost. This is then rammed and vented and the whole turned over. The top part is then prepared, and lifted off, leaving the top half of the pattern on the plate, which, in its turn being lifted, draws the other half of the pattern. Patterns for runners are also fixed on the plate so that when the plate is withdrawn, the boxes can be fixed together, the downgate and pouring basin made, and the article cast.

The plate or board for this purpose may be of wood, and if only, a limited number of moulds have to be

produced, such plates may be used with satisfactory results, but with much use the dampness of the sand affects the wood, causing it to warp, when, of course, the plate becomes useless. Consequently, wooden plates are only used in cases where small numbers of articles have to be cast, and where the patterns can be easily and quickly fastened on the plate. Generally speaking, therefore, the plates are made of iron, of which the upper and lower surfaces must be perfectly flat and parallel. A moment's consideration will show the necessity of this. During the preparation of the mould the top and bottom parts of the box are separated by the thickness of the plate. Provided that the opposite surfaces of the plate are true and parallel, the jointing surfaces of the half-moulds, when brought together after the plate with its patterns has been withdrawn, will exactly fit to each other and produce a perfect jointing. But if, however, the two surfaces are not so prepared, the jointing made will not be so good, and there is then the possibility of metal penetrating between the jointing surfaces of the two halves of the mould, producing fins on the casting, or the upper part of the casting may be out of truth with the lower.

Wooden patterns are sometimes fixed on to an iron plate; and in the case of patterns divided down the centre, one half must be fastened on its own side of the plate precisely opposite the other half on the other side. By having dowels longer than ordinary by the thickness of the plate, and passing through holes made in it, it can be easily made certain that the two half-patterns are exactly opposite each other in position. The patterns are then firmly secured to the plate. Wooden patterns are not commonly used except as above mentioned, when only a limited number of castings are required, and when the making of a metal plate

with patterns would be too costly a proceeding. But for articles of which a great number are required, or for which it is reasonable to expect repeat orders, it is better practice to have the plate and patterns cast together in one piece or to cast metal patterns and fix them to the plate. It is by no means necessary that a plate should be limited to one pattern. Several patterns may be fixed on a plate and moulded in the same box, due regard being paid of course to the making of suitable runners to each, but it is advisable when this is done to arrange that patterns should be used that do not vary in depth in the box to any great extent. If the patterns vary greatly in this respect, it will be easily understood how this variation increases the moulder's difficulty in making a clean draw of the patterns from the mould, and probably defeats the object for which moulding with plates was designed, that is, more rapid production of finished moulds. A variation of the above-mentioned method is sometimes introduced by securing the two halves of the pattern in correct position on separate plates, in effect as if the plate carrying the patterns on opposite sides had been divided longitudinally down its centre. This allows of two moulders being at work on the same mould, one forming the upper and the other the lower parts of the mould which are then assembled in the ordinary manner.

A further step in development was taken when machinery was designed which could perform some of the various operations which are comprised under the term moulding, in a satisfactory manner, and by thus reducing the physical demands made upon the moulder to increase the speed and the output. The two chief problems involved are the ramming of the sand and the drawing of the pattern, and machines for these purposes may be either hand or power driven. Among the hand

machines are those whose purpose is to obviate the work of ramming, while the patterns are drawn as usual, while in another type of machine the ramming is done by hand, the pattern is withdrawn by the action of the machine. Machines combining both these features have been designed, but the greater number of this form of machine are arranged to be actuated by some form of power, which in the foundry is generally in the form of compressed air or hydraulic power.

In the first type above mentioned, the machine is in the form of a press, the board or oddside or plate being secured on the stand of the machine and the box or snap flask being placed in position on this. The necessary facing sand is placed over the pattern, and the box is filled with floor sand to a little height above its edge. By the action of a lever a flat plate is depressed on to the sand, which is thus compressed around the pattern. The amount of sand required to fill the box on compression is easily discovered after a few trials. A reversal of the lever lifts the plate off the box, which is then strickled level with its edges, vented, turned over on a board, and removed to make way for another box which is treated in the same way. The downgate may be formed in the top part by means of a runner peg, or it may be cut out subsequently by using a pipe.

The disadvantage of the press is the unequal compression which is bound to occur because of the varying depth of sand in the box, on and around the pattern. Attempts have been made to overcome this difficulty by fixing shaped boards on to the pressure plate, thus to a great extent equalizing the pressure, but at the same time considerably increasing the cost.

A further improvement in ramming has been introduced by the designing of the jolt rammer, a machine

which can be used for all types of box moulding, heavy and deep work being satisfactorily rammed on it as

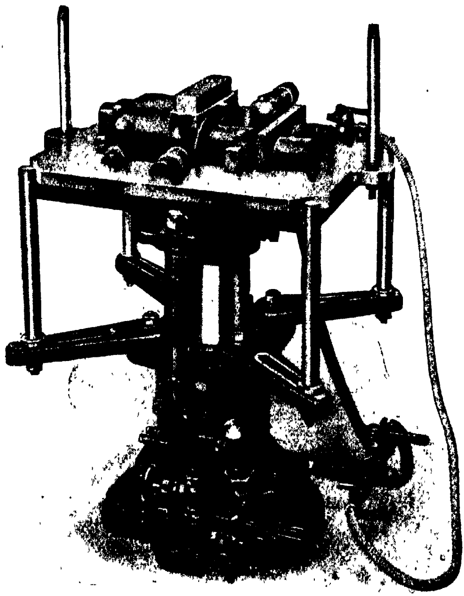

FIG. 19.
JAR RAM MOULDING MACHINE
(The Britannia Foundry Co.)

well as light and shallow work. In this machine patterns, boxes, gaggers and all other necessary parts are securely fixed on to the table of the machine. The sand is then filled into the box, and the table then receives

the number of jars or jolts which experience has taught are required for the proper ramming of the sand of that particular depth. By these jolts the sand is driven against the plate and pattern, the ramming effect being most pronounced where it is required to withstand the subsequent pressure of the molten metal, while at the same time the sand is so evenly pressed together that very little use of the venting tool is needed, and many castings are made in moulds which, having been rammed on a jolting machine, are assembled without the venting tool having to be used at all. Machines working on this principle have been made which will satisfactorily ram very large moulds, resulting in a great saving of time and energy.

In the second type of hand machine as previously mentioned, in which the pattern is withdrawn by the action of the machine, the ramming is frequently done in the usual way by hand. In the actual drawing itself there is a choice of two methods, the pattern being either drawn away from the mould which itself is fixed, or the reverse process may be adopted, the mould being drawn from the pattern, this being itself held rigidly. In either case it is customary to interpose a stripping plate between the pattern and the sand to hold the sand in position while drawing takes place. The stripping plate is usually a wooden plate, the centre or other portions of which are cut out to correspond exactly to the shape of the pattern or patterns, which are made greater in depth by the thickness of the plate to allow of their passing through the holes in the plate to their exact parting. The sides of the cuts in the stripping plate are slightly tapered to allow of an easy draw, and the object in using a stripping plate, that is the prevention of the displacement of any portion of the mould during the drawing of the pattern, an occurrence

which might easily take place if no preventive means were adopted, will be readily appreciated.

In the various machines arranged for drawing the patterns, the result is attained by several methods. In one machine the pattern is mounted on a plate which, by a downward sinking movement, draws the pattern through the stripping board until it is below the level of the box, which can be lifted off the machine. Another machine works on a different method, the pattern and box being clamped on a plate which can swing over by means of swivels at the centres of opposite sides or by arms which swing it over. The mould being rammed, the plate carrying the mould is overturned. A table forming part of the lower portion of the machine, and which can be elevated or depressed in a vertical manner by means of screws or levers, is then raised till it bears the box. This being unclamped from the revolved plate to which it was fixed during ramming, now rests on the table unloosed from its patterns. As the table is lowered it carries with it the box, leaving the patterns on the revolving plate, which can be turned over to prepare another mould, the finished one being removed. In yet another type of machine the stripping plate lying over the pattern engages with studs on a lifting table under the pattern which remains fixed. To draw the pattern a lever forces the lifting table with its studs upwards, thus raising the stripping plate and mould to a sufficient height to clear the pattern, and the box can then be detached from the machine.

At first sight it does not seem that a machine designed to draw the patterns from a mould which may have been hand rammed would effect any great saving of time. But when it is considered that in most cases when a pattern is withdrawn by hand or by crane it is almost impossible to get a perfectly clean draw

because of the conditions, and consequently a greater or lesser amount of mending is necessitated, while in the case of the machine draw, the rigidity of the machine and the steadiness of the movement during the removal of the pattern, enable perfectly-formed moulds to be regularly produced, the great saving of time because of the greatly-reduced amount of mending required becomes apparent.

Hand machines have been successfully designed which embody both the action of the press and the draw, but it will be understood that all the hand machines are only of use in the making of moulds of comparatively small size, any larger dimensioned articles are moulded on machines which are actuated by some form of power. In these machines the press, the revolving plate, the rising and falling table in some form or other provide the principal features, and the motive power is usually either pneumatic or hydraulic.

A very important and ingenious device which forms part of all power machines and is very frequently found on the hand operated machine is the pneumatic rapper ; which by a series of rapid but light taps effectively detaches the sand from the pattern before drawing, exactly in the same way as the strokes delivered by the moulder as described in Chapter VII.

The necessity for accuracy of fitting has been pointed out in dealing with the preparation of the plates and patterns for plate moulding. The same necessity exists in all forms of machine moulding, and the lugs of plates, stripping boards and boxes must be accurately drilled and fitted, as it will be obvious that any inaccuracy of fit on the part of the finished mould is absolutely fatal to the production of perfect castings.

The possibility of obtaining the best results from any machine introduced into the foundry does not

altogether depend upon the number of moulds that it is possible for it to turn out in any given time. In a great number of instances the machine-made moulds require coring, and the capacity of the machine is thus limited by the number of cores which can be produced for that particular mould, and again by the number of boxes which are available for its special work. It follows, therefore, that a reorganization of the foundry may be necessitated by the introduction of machines, and unfortunately it sometimes happened that machines have been condemned as not fulfilling their purpose, when owing to the conditions existing in that particular foundry it was not possible to utilize the machine to anything like its full extent, and thus reap the advantage which might have been obtained had conditions been favourable.

It will be understood that in the event of any mould requiring cores these have to be fitted in the usual way, and in general the closing of the boxes still remains to be done by the workman.

CHAPTER XI

CORES

CORE-MAKING is a separate branch of the moulder's trade, as previously mentioned in Chapter VI. As its name suggests, the core of a mould is that portion which produces in the finished casting its internal shape and dimensions, or which cuts out metal leaving recesses or holes in the mass, and it will be obvious that according as the interior of a casting is required to be of simple or intricate form, so the core which forms the interior will be of simple or intricate design. A core may be so simple in its design and method of production that a boy may make it with great ease and rapidity, or it may be so involved in its construction as to tax the skill and ingenuity of a first-class workman and take him many hours to complete. The same conditions of strength and porosity which apply to the outer portions of the mould must be observed in the case of the core, but to a greater degree, for the simple reason that while in the outside portion of the mould the action of the metal is felt on one face and a connection is easily maintained with the outer air, the core is often almost entirely surrounded by the molten metal, and the gases which have to be led away can frequently only escape through a narrow section. This necessitates that in the making of a core it is essential to use a strong sand, and often to increase its binding power by using adhesive substances which are not required in the ordinary mould. Many different materials are in use for this purpose, among them the substances known as

core gums, which are generally made by treating starch or starchy materials with sulphuric acid, and other gums obtained as by-products from the residue left in the manufacture of wood pulp. Flour of different kinds and resin have also been used, as also have treacle, yeast and some of the drying oils of different descriptions. These oils produce cores of a strong nature and are somewhat extensively used. It is also necessary that the porosity of the sand is of a highly satisfactory character and the venting arrangements perfect.

A further condition is imposed upon cores that does not fall upon the mould itself. The hot metal after solidifying contracts as the temperature decreases, and this exerts a tremendous compressive force upon the core from which the outer section of the mould is free; and if the core be composed or built up of unyielding material, stresses are set up in the metal which may ultimately be of such magnitude as to result in the cracking of the casting, a phenomenon which has not infrequently happened. Consequently the core, while being strong enough to withstand the metal on its pouring, and being perfectly porous and well vented to allow of the escape of all gases generated, must be made of such a nature, either by reason of its own compressibility, or because of other means adopted to reduce its size on the completion of solidification of the metal, as not to produce strains or cracks in the finished casting.

Just as in moulding the sand may be used in different conditions and cores are designated green sand cores, dry sand cores, or loam cores according to the condition of the material and the methods employed. Another classification of cores might be as to whether the pattern itself is made to produce its own core, or the cores have to be made separately from the mould and then

fitted into position. The latter is the more general type, the former consisting mainly of those comparatively small circular or rectangular articles in which the internal section is fairly similar to the external section, such as small wash boilers or tanks, the larger castings of such type being generally made in loam.

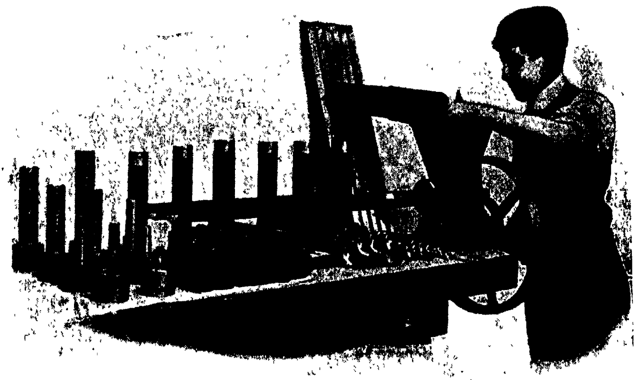

FIG. 20.
CORE MACHINE FOR CORES OF CIRCULAR SECTION
(Messrs. Geo. Green & Co.)

As a general rule, the majority of cores are made separately from the mould, and are classified as green sand, dry sand, or loam cores respectively.

As cores have in most cases to be handled, it will be appreciated that this forms a difficulty in the case of green sand cores which require very gentle and delicate manipulation, and this factor enhances the value of dry sand cores which are capable of withstanding much

more handling than cores in the green state. Nevertheless green cores are successfully made, and in some instances afford the readiest means of dealing with contraction in those parts of the mould where other methods are not applicable. Very intricate and difficult cores are frequently made in sections, each section forming a comparatively simple problem, and these are in some instances pasted together by claywash or core gum forming the complete core. In other instances one section may be fitted into prints formed in other sections, thus completing the core.

Many cores, being supported in the mould in places removed from each other, carry a considerable quantity of sand, which, as in the case of large masses of sand in the mould, would tend to break off or fall apart if not properly supported. To obtain this support, wires, rods and irons of sizes and shapes most suited to the purpose are fixed in the sand while the core is being made, and these serve to give to the core the strength and rigidity it needs.

Cores of irregular shape or large size are usually made in wooden boxes, the interior shape of which is the counterpart of what the core is desired to be. Such boxes are made in sections which can be fastened together either by staples driven into the wood, this, however, having a detrimental effect on the boxes, or by some form of latch, by which means the extraction of the core when made is a simple matter. Long thin cores which would tend to break if unsupported are strengthened by rods fixed along the centre while the core is being rammed up. In other cases core irons, which are usually roughly of the shape of the core they are intended to support, and which are frequently cast on the floor of the foundry, are embedded in the sand. Core irons vary in shape and size according to the

differing sizes and shapes of the cores, a common form consisting of a bar with projecting arms on either side, while for large cores of circular or similar section the core iron may resemble a fire basket.

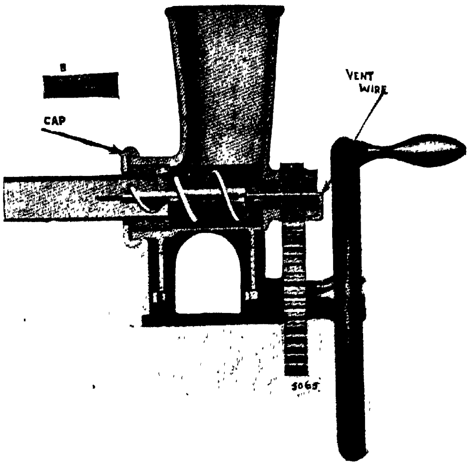

FIG. 21.
SECTION OF CORE MACHINE
(Messrs. Geo. Green & Co.)

The core-maker rams part of his box with sand, and then fixes his iron, which he often dips in claywash to give greater adhesion, in position and proceeds to complete the ramming of the core. The venting has now particular attention for reasons previously specified, and the core is released from the box and usually treated with blacking generally in a liquid state. In cores of peculiar shape or of such section that it is not

possible to vent by the use of the ordinary tools, special methods have to be adopted to provide the necessary passages for the escape of the gases. The usual method in such cases is to build into the cores lengths of wax taper or thread somewhat similar to the ordinary wax taper, care being taken that all the lengths placed in the core are in connection and leading to some external outlet. On the core being dried the wax is melted and absorbed by the sand, thus forming a series of channels for the passing of the gas which, when the molten metal is poured into the mould, are still further enlarged by the burning of the cotton or other fibres of which the tape or thread was composed, thereby allowing ample room for the passage and escape of the gases. It is then placed in a drying stove until the moisture has been completely evaporated from it. The drying of the core leaves it much more porous than before, and because of the binding material mixed with the sand, much stronger than in its green state. Care has to be exercised in the drying of the cores that the temperature of the stove does not rise to a point sufficiently high as to affect the gums, or starches, or resins, or oils which have been used as binders. If this happens, the bonding properties of these substances will be destroyed and the core spoiled. It has been found that oil cores are among the strongest cores made and they possess an advantage in that if not required as soon as they are dried, they do not absorb moisture from the atmosphere as cores made with other binders are liable to do. The consideration of the materials used as binders in cores gives special emphasis to the necessity of perfect venting in this part of a mould. The effect of the intense heat on these materials is to produce large amounts of gas, which if not able to escape by means of venting channels will seek other avenues of escape,

which means, of course, through the molten metal, thereby increasing the possibility of blowholes and similar defects in the casting.

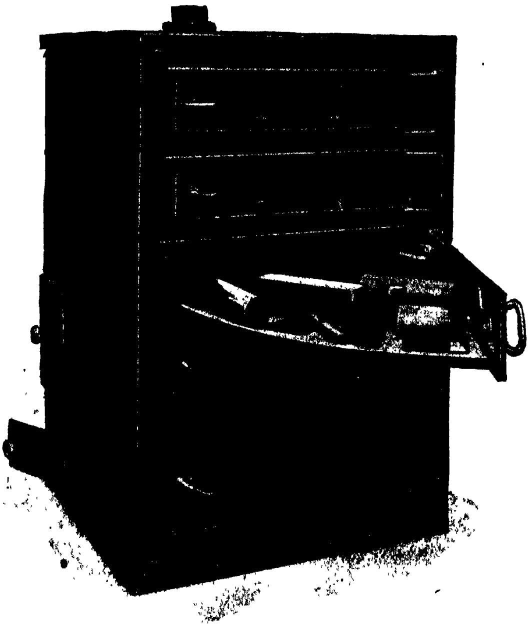

FIG. 22.
CORE STOVE
(Messrs. Geo. Green & Co.

Many castings require a number of cores, and this has led to the introduction of machines for the making of the numbers required. For instance, a large number

of cores of circular section and of various diameters are continually being used for such purposes as coring out bolt holes and the like. These are generally made by means of a machine somewhat like the familiar sausage-filling machine in appearance, in which the sand is forced through a tube of the required section by a screw motion, emerging on to a tray which can be transferred to the oven when filled with the lengths of core necessary. The necessary venting is automatically secured by a hole running down the centre of the length of the core, which is made by a wire projecting beyond the point of the screw. Other forms of machine for core-making are similar to the press machines used in the making of moulds, while others again consist of boxes out of which the core can be pushed by lever or pneumatic power when completed.

The majority of cores made in loam are of circular section and are made by the use of core barrels which form the strengthening core irons. The cores for large pipes, for example, are fashioned on a core barrel, which is a hollow cylinder pierced with many holes on which loam is laid to the requisite diameter of the core. Previous to the application of the loam the core barrel, which is placed on trestles so that it may be easily revolved, is wrapped round with a rope made of straw which, burning when the heat of the molten metal reaches it, allows of sufficient contraction in the core. On the straw rope is spread loam, plastered on while the barrel is kept in motion, till a sufficient amount is laid on to nearly give the required thickness of core. A board is then moved up to the revolving barrel and the loam is of course swept to the correct size. The usual treatment of blacking and drying follows, but it is needful to be specially careful in the drying of loam cores with straw band, that the straw is not charred

in the drying, as this would leave a soft place in the core which would in all probability result in a defective casting.

The type of stove in use for drying purposes will naturally depend upon the size and type of core which is being made. For small cores, stoves are made to be heated by gas and fitted with shelves for the reception of the cores, each shelf of which can be withdrawn for filling or emptying without disturbing any other shelf and with no appreciable loss of heat. Larger cores will necessitate the provision of larger stoves with the necessary shelves or trestles upon which the cores of varying dimensions and shapes can rest while in the process of drying. Modern stoves are frequently heated by producer gas, but heating by means of coke or coal is still carried on.

CHAPTER XII

PERMANENT MOULDS

THE whole of the moulding which has been dealt with in the previous chapters has been in connection with sand. Because of its refractoriness and the bonding properties which it possesses sand, as has been seen, lends itself to the production of moulds which have to withstand the high temperatures of the foundry. But sand moulding has one outstanding defect, which is, that after one single casting has been made from a mould, which may have involved long and arduous labour and careful preparation, probably on the part of several men, that mould has to be utterly destroyed to release the casting; and if a second similar casting is required another mould must be prepared. Many attempts have been made to construct moulds which should be able to be repeatedly used in the production of numbers of articles of the same form. The greatest degree of success in these attempts has been attained by the use of metal moulds. In those trades dealing with the non-ferrous alloys, metal moulds are extensively used for the production of various types of castings in white anti-friction alloys in brasses and in bronzes. Moulds of this description are known as chills, or dies, or permanent moulds, and while they have not been used to the same extent in the casting of iron as in the casting of non-ferrous articles, they have been used with satisfactory results. Chill or die casting is the general term by which the process is known.

It will be quite obvious that, because of their considerably lower melting point, it will be possible to deal with the non-ferrous alloys in a manner that is impossible with cast iron, and so various means have been adopted in connection with these alloys and die casting which have never been applied to iron. By the use of special machines it is possible to force these metals under pressure into the permanent mould or die, and several machines are now on the market for this "pressure die casting." But very largely because of the much higher temperature of molten iron, and the greatly increased difficulty of planning, constructing and maintaining any machine parts to withstand this higher temperature, the method of producing castings under pressure has not been applied in the iron industry, so that casting in permanent moulds or die casting when used in the foundry simply refers to the making of castings in iron moulds, the metal being poured into the metal mould as in the case of sand castings.

It is generally only in those cases in which the castings have a plain cylindrical interior where it is possible to make the complete mould of metal. It will be obvious that in the case of a casting which requires an intricate core, it will be a much simpler and more convenient plan, even if the exterior form of the article is made by means of a permanent iron mould, to use the ordinary sand core for each casting rather than to attempt to provide metal cores. To suggest only two problems in connection with metal cores, expansion and extraction, it will be seen that an immense amount of experiment and considerable ingenuity will be required to produce a satisfactory permanent core of intricate design. This of course would necessitate somewhat heavy expenditure, and for this reason alone sand rather than iron cores are used if of intricate design in permanent moulds.

Just as has been pointed out in the chapter on machine moulding, the full benefit of a permanent mould can only be realized when there are large numbers of castings of the same type to be produced, and this again points to more extended standardization. As a direct result of the years of war, the use of permanent moulds has largely increased. Such articles as cast iron shells, shell parts, such as fuse sockets and bombs, have been produced in enormous quantities by means of permanent moulds, and even in pre-war time articles such as fire-bars, large gear blanks, wheels, and similar articles were frequently cast in such moulds, while articles which depend for their efficiency upon the possession of a hard chilled iron surface such, for example, as the rolls for rolling mills, brake drums, car wheels, and hub liners were very extensively produced by their use.

The material which is most generally used in the making of permanent moulds is cast iron, the greater mass of opinion being that this metal is the most suitable for the purpose, and produces the most satisfactory results. This was confirmed by Messrs. Rix & Whitaker in a paper read before the Institute of Metals in July, 1916 (*Jour. I. of M.*, July, 1916, No. 2), giving a description of their production of aluminium bronze castings in permanent moulds, in which they state that cast iron moulds gave them their most successful results. The reasons for this superiority are not yet definitely understood, but Mr. J. E. Hurst, in a paper given before the Foundrymen's Annual Convention held in Liverpool in 1919, attributed it to the irregular contour of the tooled surface of the die caused by the presence of the harder and softer constituents of the metal, forming tiny reservoirs in which very small amounts of air and gases are entrapped between the surface of the metal mould and the molten metal during pouring, thus

forming a gaseous film which prevents the adherence of the molten metal to the mould itself, and allowing of the casting being withdrawn possessing a clean and smooth surface. From this point of view, the use of some form of mould dressing compound composed of carbonaceous materials is of assistance in producing, on coming in contact with the molten metal, this gaseous film from the gases which are evolved.

In a previous paragraph mention has been made of the value of permanent moulds in the production of articles which require to be excessively hard on the surface, which hardness is due to the formation of a skin of white iron on the casting due to the very rapid cooling of the metal on reaching the surface of the mould. In castings, however, which are required to be machined, the production of this unmachinable white iron skin renders such articles of no value, and the difficulty of avoiding or obviating the formation of the white iron exterior is one of the objections to the use of permanent moulds. But as explained in Chapter III, other factors beside the rapid cooling of the metal may help to determine the condition of the carbon in the finished product, and so by suitably controlling the composition of the metal and arranging for a sufficiently high silicon content, the danger of producing an unmachinable skin may be entirely eliminated.

In connection with the use of cast iron for the making of permanent moulds there is introduced into foundry practice several difficulties which are not experienced in connection with sand moulding. Some of these difficulties such as the cracking of the whole mould or the distortion of parts of it can generally be attributed to defective design in the making of the mould resulting, when the molten metal enters, in differing degrees of expansion in varying parts of the mould, thus creating

internal stresses which produce the distortion or rupture. Such difficulties may be obviously avoided by having moulds more correctly designed. Blow-holes are sometimes occasioned in permanent mould castings from the same cause, i.e. faulty design. On the pouring of the metal into badly-designed moulds it may happen that comparatively large amounts of air may be entrapped, which, in attempting to escape through the metal, produce blow-holes. The remedy for this occurrence is of course to design the mould in such fashion that the incoming of the metal sweeps out the air and gases in its course. Pinholes are frequently noticed in castings made in moulds of this description, but it has been observed that this trouble is much more frequent when the mould has seen considerable service and is becoming worn, and it is patent that this type of defect can best be remedied by the scrapping of a mould in this condition and the use of a new one.

But some of the above difficulties may also be occasioned by what is known as "growth." Profs. Rugan and Carpenter investigated this peculiar phenomenon, and in their now classical memoir explain that it comes about because of the penetration into the interior of the cast iron of gases which, acting upon the constituents of the iron in an oxidizing fashion, produce permanent enlargement sometimes to a remarkable extent. There does not seem to be any method of counteracting this defect that is generally applicable, but it is recommended that the blocks of cast iron of which the mould is made should have themselves been cast in a permanent mould. When this procedure is followed the life of a permanent mould is usually sufficient for all commercial purposes.

For two very important reasons it is almost inevitable that this type of casting will in the future be more

extensively adopted. In the first place, a much more closely grained and, from the metallurgical standpoint, a considerably improved product is the result ; and in the second the present economic position of the foundry trades is rapidly compelling the adoption of all processes which will reduce the heavy labour costs, and which lend themselves to mass production. The following example of this tendency is gleaned from contemporary American journals, in which it is stated that the building of a foundry for the production of radiator castings in permanent moulds is contemplated. This foundry is to be highly organized for the special production of this type of casting, and the whole of the moulds will be operated and handled in chronological order by machinery, and the finished castings removed by mechanical conveying appliances.

A process for the production of castings has been devised which is allied to permanent mould casting, and has also features in common with pressure die casting, and which is being successfully worked. This process, known as the "Centrifugal Process," consists of the introduction of molten metal into a rapidly-rotating metal mould, under which circumstances the metal solidifies rapidly under the influence of centrifugal pressure and rotary motion. Castings produced by this process possess enhanced physical properties.

CHAPTER XIII

MALLEABLE CASTINGS

It will be fully appreciated from what has been said in Chapter III that grey cast iron is at the best a brittle material and possesses only minute traces of ductility when measured by elongation in making the tensile—or pulling test. This is essentially due to the form in which the free carbon exists, that is in the form of graphite existing as plate-like bodies forming weak boundaries between the component crystals. In fact, ordinary grey cast iron may be considered almost as a plain carbon steel with the addition of graphite plates between the crystals. It will be easily understood how this state of existence of the carbon modifies the ductility of the material rendering it very brittle. In those cases where castings are required to possess any degree of ductility and resistance to brittleness it is necessary to resort either to steel castings or to castings made from cast iron treated in such a manner as to render it partially ductile or malleable, such treated castings being known as malleable castings.

The earliest record of malleable cast iron is to be found in the account of the experiments of the French scientist Reaumur published in a paper entitled *L'art d'Adoucir le Fer Fondie* in the year 1722, who found that on subjecting samples of white iron, which is extremely hard and brittle, to prolonged heat treatment in contact with iron ore or red oxide of iron, they became soft and malleable. These experiments formed the basis of what is now known as the Reaumur or Old English malleable cast iron process.

In this process, castings of the hard, brittle white iron are subjected to prolonged heat treatment while packed in iron boxes along with finely divided hematite ore in specially constructed furnaces. After this treatment, it is found that the castings have become soft, malleable and ductile, so that they can be bent to a considerable angle without fracture taking place. The theory underlying this process has been constructed from the results of the investigations of numerous metallurgists and scientists. It has been shown to be essentially due to the removal of the carbon, which, it will be remembered, exists in white iron as a solution of the chemical compound carbide of iron in iron, by the oxidation of the carbon portion of this compound on the surface layers of the casting in contact with the oxide of iron, forming carbon dioxide gas (CO_2) which is evolved during the process. The continuation of this oxidation into the centre of the mass of the casting is brought about mainly by a kind of double process. One portion of the process consists in the penetration into the interior of the casting of the carbon dioxide initially formed at the surface. On penetrating, a further reaction takes place whereby it oxidizes a portion of the carbon according to the formula $CO_2+C=2CO$, carbon monoxide being liberated, which is again re-oxidized on coming into contact with the hematite ore. The other part of the process consists in the gradual diffusion of the carbide constituent from the centre of the casting to the external layers, which, by reason of the removal of some of the carbon during the initial stages of the process, have become less concentrated with carbon. As it diffuses towards the external layers of the casting, this carbide constituent is in its turn oxidized in a like manner, until the whole mass of the casting has been affected. The total effect of the

complete process is the partial removal of the carbon by oxidation, as is illustrated by the two following analyses of white iron before and after heat treating according to the Reaumur or Old English process—

	White Iron.		Old English.
	%		%
Combined Carbon	3·5		·65
Graphite	Nil	Temper Carbon	1·1
Total Carbon	3·5		1·75
Silicon	·5		·50
Manganese	Traces		Traces
Sulphur	·35		·35
Phosphorus	·05		·05

W. H. Hatfield.—*Cast iron in the light of recent research.*

It will be noticed from these analyses that a considerable quantity of carbon still remains in the heat treated malleable sample, and further, that a portion of this exists in the free state. This free carbon is formed as a result of the decomposition of the residual amount of the chemical compound carbide of iron after prolonged heat treatment, and exists in a characteristic nodular form as illustrated in the microphotograph Fig. 23 given on p. 117. The round black nodular areas in this photo are found to be full of carbon in an extremely finely-divided form, totally different from the graphitic plate-like form noticed in grey iron. On this account it has been separately identified under the title of annealing, amorphous, or temper carbon. It will be quite easy to appreciate the fact, on comparison of the above microphotograph, with those given of grey iron in a previous chapter, that the free carbon existing in this peculiar form exerts very little influence on the mechanical strength properties, particularly of brittleness and ductility, as, different from the plate-like formation of graphite in grey iron, it offers no continuous path for the production of fracture.

It has been pointed out above that the residual

carbide of iron in the white iron decomposes after subjection to prolonged heat treatment, giving rounded

FIG. 23.
MICROPHOTOGRAPH SHOWING NODULAR AREAS OF CARBON

nodular areas of amorphous or annealing carbon. This fact has formed the basis of a second process of manufacture of malleable castings which is extensively used

in America. It consists in subjecting to a long period of heating, the white iron castings which are packed in boxes in a similar manner to that which obtains in the Old English process along with hammer scale, sand, cast iron boring or turnings, or any other material not of an oxydizing nature, the action of the packing material being simply to prevent excessive scaling of the castings when exposed to the heat. As a result of this prolonged heat treatment the greater portion of the carbon existing in the combined form is decomposed as stated above and is converted into extensive nodular areas of annealing carbon throughout the mass of the casting. This transforms the casting from a hard and brittle white iron into a soft and malleable material. The fracture of this material presented by a broken bar, unlike that of the Old English or Reaumur material which presents a bright steely fracture, is of a dull blackish grey. The edges of the fractured material usually show a comparatively thin case of bright steely fracture, the result of a slight amount of superficial decarbonization. This peculiar type of fracture has given rise to the name "Blackheart," which is applied to castings made by this process.

Of the two processes the former is more extensively used in this country, and the annealing of the white iron castings is carried out in muffle-type furnaces, variously fired with coke, coal or gas. The temperature to which the castings are subjected is usually in the neighbourhood of from 950° C. to 1,000° C., and the length of treatment varies according to the thickness of the castings being thus treated, being from 24 to 2,000 hours. The packing used is mainly hematite ore consisting chiefly of red oxide of iron, and as free as possible from lime and other fusible constituents, which would fuse to the castings forming hard slag-like material

on their surfaces. This ore is crushed, washed and graded to about the size of peas, and the boxes usually packed with a proportion of this new material mixed with material which has been previously used for the same purpose.

In castings made by this process considerable distortion invariably takes place during the heat treatment, and the extent and importance of this distortion depends entirely upon the thickness and shape of the castings being produced. Various means are adopted for preventing this distortion taking serious forms, such as by strengthening and reinforcing the casting with wrought iron bands and hoops before the treatment commences, and there is considerable room for ingenuity on the part of the malleable iron-founder in devising methods with this end in view. In the ordinary course of events a considerable amount of straightening and shaping is required on the castings after heat treatment, and after they have been withdrawn from the furnace, allowed to cool, fettled, pickled and sand-blasted, the castings are straightened either by the use of a hammer or, in the case of repetition work, small straightening dies may be made, and the articles rapidly straightened and the shapes corrected by the use of hand or power presses.

In the "Blackheart" process practically the same procedure is followed with the exception that the temperature of heat treatment, after being raised for a short period to the region of 950° C., is maintained at the lower level of between 750° C. and 800° C., till the completion of the process, when the castings are withdrawn, cooled and treated in a like manner.

It has been previously pointed out that the initial material in which these castings are made is white iron. This is the same in both processes, and in order to obtain satisfactory results considerable care and

attention has to be paid to the control of the composition of the material used. The chemical elements present in white iron are identical with those present in grey iron, but with, of course, the difference of the condition of the carbon content. In all malleable castings phosphorus is extremely detrimental, and on this account hematite pig iron only is used in this connection and special hematite irons are usually to be obtained for this purpose. In the Old English process sulphur is not an undesirable constituent, and because of this the comparatively high sulphur content which is invariably associated with low silicon white iron, blast-furnace pig is not detrimental to the process.

In the "Blackheart" process, however, it is desirable that the sulphur content be kept as low as possible, or otherwise considerable difficulty is experienced in obtaining successful results after annealing. In both processes it is desirable that the content of manganese in the iron be kept as low as possible, and a figure in the region of about ·4 per cent represents good practice. In like manner in both processes the silicon content is of vital importance. It is essential in order to obtain the best results with the final castings, that the original white iron castings be entirely free from graphite which involves low silicon. At the same time it is also necessary in order to obtain the most rapid and successful change from the white to the malleable condition on annealing that the silicon content should be as high as possible without the production of graphite in the original white iron casting. In actual practice the silicon content of the white iron casting is usually kept in the neighbourhood of ·7 per cent to ·8 per cent. It is also good practice before the casting commences to take frequent samples of iron from the furnace and cast these into bars of about the average thickness of

the castings being produced, which bars are then broken with a view to ascertaining if any graphite is present in the white iron.

In the Old English process the total carbon content is not of extreme importance, whereas in the American process, somewhat better results are obtained with a fairly low combined carbon content material. This accounts for the fact that metal melted in the air furnace, in which a slight loss in the carbon content takes place by oxidation, is very satisfactory for use in the production of castings by the blackheart method. Cupola melted metal is most extensively used in this country for the Old English method, and the fact that there is no reduction in the total carbon content in the cupola cast metal offers no detriment to the use of this form of melting.

A comparison of the mechanical properties of malleable cast iron with those of grey cast iron is made in the following table, and the difference in ductility as measured by the elongation is clearly brought out, as is also the difference in brittleness as shown by the angle of bending.

	White Iron.	Malleable Iron. (Reaumur).
Maximum Stress	9·8 tons per sq. in.	30 tons per sq. in
Elongation	Nil	3%
Bending Angle	Nil	42°

J. E. Hurst.—*The Engineer*, 2nd Aug. 1918.

The procedure following in the making of the moulds for white iron castings is practically the same as that followed in the case of ordinary castings, but there are one or two special difficulties to be overcome which are not met with in grey iron practice. It was pointed out in Chapter III that one of the most valuable assets of grey iron for the making of castings was its low shrinkage, which is accounted for by the formation of the graphite

from the carbide of iron as the material cools. It will be obvious that in the case of white iron castings in which there is no graphite formed, the shrinkage will be much greater than in the grey iron. This greater shrinkage has to receive the special attention of the maker of white iron castings; and in some instances an extra allowance is made by the pattern-maker for this shrinkage over and above that made in patterns used in ordinary foundry practice. In addition to this greater shrinkage there is also the difficulty caused by the lesser degree of fluidity of white iron as compared with grey, which is the result of the considerably smaller amounts of phosphorus and silicon permissible in the material. These two properties of white iron necessitate the making of larger gates, runners and feeders than are required in the casting of grey iron, in order that the metal may be kept fluid for as long a time as is necessary to completely fill the mould and to allow of the feeding of the interior of the casting for a period after the outer portion has become solid, and because of its shrinkage has begun to take up metal from the still fluid interior.

CHAPTER XIV

DEFECTS IN CASTINGS

THE ideal foundry would be one in which every mould that is made produces a perfect casting, but unfortunately such a condition of affairs has not yet existed, and trouble is often experienced by buyers of castings through rejection due to various causes. A large portion of these defective castings can be located before the castings leave the foundry, and every endeavour should be made—and is made in up-to-date foundries—to eliminate defectives before delivery to customer or machine shop by an efficient inspection system. The adoption of a system of inspection possesses an additional advantage in that it facilitates the detailed study of particular defects on the spot, and thus enables means to be taken to prevent as far as possible the recurrence of those particular defects.

Efficient inspection generally discovers that defects in castings can be grouped into two classes; defects which are caused as a direct result of the moulding, and those which are due in some way to the metal. In addition to these, castings are frequently rejected or defects arise in them which can be directly traced either to the design of the article or to the subsequent treatment it has undergone in the engineering shops. Faulty design is frequently responsible for increasing the difficulty experienced in making satisfactory castings, and this arises as a result of a want of familiarity on the part of the designer of the fundamental principles underlying the production of castings. In general, these difficulties are caused by the joining on to large

masses of metal of portions of much thinner section, or to the leaving of rectangular corners in the design. In the first case difficulty is experienced owing to the different rates of cooling of the thick and thin sections, giving rise to unequal shrinkage, the thin section also being the first to solidify tending to draw away metal from the still molten thicker portion, with the result that the metal at the junction of the two sections is left very weak, frequently with holes (drawholes technically) in the interior of the metal. If the design allows of modification without interference with the suitability of the article for the purpose intended this difficulty can be largely overcome by the addition of fillets to the thinner section bringing about a more gradual reduction in the difference of the rate of cooling in the sections and consequently reducing the unequal shrinkage; but if the design cannot be adjusted in this way, a rapid quickening in the rate of cooling of the larger mass of the metal is brought about by the use of "chills," which are pieces of metal embedded in the mould for the purpose of rapidly conducting away the heat from the larger mass, and bringing about much more rapid solidification in that part of the casting.

In the second case, the manner in which crystallization takes place in the metal has to be taken into account. The metal first solidifies on the outside, and the crystals grow inwards at right angles to the cooling surface. At a rectangular corner there is thus a plane of confused crystallization due to the meeting of two systems of crystallization proceeding at right angles to cooling surfaces which are themselves in different planes; and this plane of confused crystallization is a weak section, not only from the point of view of strength, but also from its less ability to withstand pressure, and its consequent liability to leakage, if the casting be

required to be tested or used under hydraulic or steam pressure. The remedy for this defect is to round the external corners and fillet the internal ones, so that the line of crystal growth may be more or less radial.

In the case of those castings which are rendered defective by their subsequent treatment in the machine shops, this may be caused by the methods employed in machining. In the modern rapid method of production, castings are often required to be machined in jigs, by the use of which the whole of the machining operations are standardized. Jigs, being designed for accurate repetition work, frequently do not allow of sufficient allowance being made for the unavoidable inequalities and inaccuracies which occur in castings, no two sand castings being absolutely alike, and castings that are otherwise perfectly good and sound may be spoiled by the jig being positioned on some part of the casting which from some cause or other was not of sufficiently accurate dimensions as to allow of the machining of the rest of the casting to the requisite size.

A greater number of castings are spoiled because of faults in the mould. By the preparation of a badly-jointed mould, that is, one in which the two halves of the mould do not fit properly to each other, or by the insufficient weighting or cramping of the boxes together so that the pressure of the metal lifts the upper part, or because the cores do not accurately fit into their prints, or because of the poor fit of the boxes, metal may be able to force its way out of the mould, causing what is technically known as a "run out." In a well-equipped and well-regulated foundry events of this type should be very infrequent occurrences, but if a run out does occur, the moulder endeavours to stop it by pressing sand on the leak, when the escaping metal solidifying prevents any further leakage.

The breaking down of the face of any part of the mould during the casting operation is responsible for the spoiling of many castings. This may occur from a

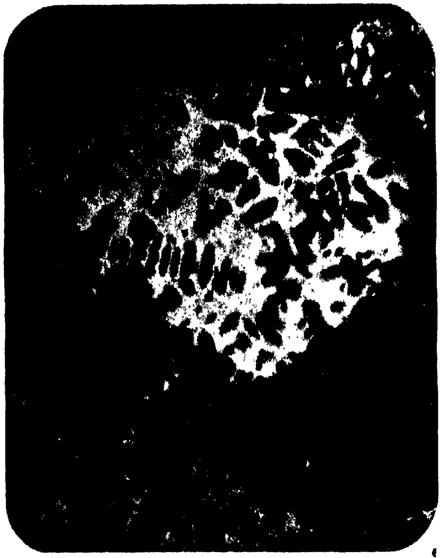

FIG. 24.
MICROPHOTOGRAPH SHOWING SHOT OR PELLET

variety of reasons; irregular or too hard ramming or faulty venting, or the too rapid rush of the metal into the mould, may cause portions of the mould face to become detached, which therefore alters the shape of the mould at that particular point, the result being a

hump or "scab" on the casting; while the sand which has broken away becomes dirt in the metal and is frequently incorporated in the casting, producing a "dirty casting."

One of the commonest defects of castings is usually the result of the use of too wet sand in the moulding. This results in the ramming producing a mould which is not sufficiently porous, and consequently when the molten metal enters the mould, the superfluous moisture is changed into steam which, along with the other gases, finds difficulty in escaping through the sand. It is therefore driven to escape in some other way, and the only other way lying through the metal, it tries to bubble through this, but owing to solidification taking place before it has escaped it is frequently entrapped in the mass of the metal, causing defective castings through "blowholes." The appearance of blowholes from this cause is certainly a reflection on the judgment of the moulder as to the condition of his sand, and may be the result of carelessness or of inexperience.

In the pouring of the metal it occasionally happens that the first metal entering the mould strikes a projection or splashes into the mould. These splashes immediately solidify, forming round shot, which is incorporated into the mass of the metal and is not always remelted. If such shot are held near the surface of the metal, on grinding or machining a ring round the imperfectly fused shot can be observed.

Other defects in casting are sometimes due to the temperature of the metal at the time of casting. The hotter the metal the more fluid it is and the more easily it will run. In castings of thin section, if the casting temperature is not correct, it will sometimes happen that the metal will solidify before it has run its course and completely filled all the interstices of

the mould. The thicker sections may be perfectly cast, but the thinner sections, owing to the rapid solidification, have not been completely filled. As has been previously mentioned, it is usual to fill the mould by means of a spray or sprue of runners to ensure the proper filling of each and every part of the mould. But even with this precaution, if the metal is not of sufficiently high temperature, it sometimes occurs that the streams of metal have become so reduced in temperature that, though they fill the mould, they are not fluid enough to perfectly join or weld together and the point of meeting can be distinctly seen and renders the casting defective. The obvious way to ensure good castings from this point of view is to pour with metal of a sufficiently high temperature.

The chief defects due to the composition of the metal are excessive shrinkage, and as a result of this frequent cracking of the metal, and too great hardness throughout the mass of the metal, or the existence of hard spots at particular parts of the castings. These may generally be considered due to the small amount of graphitic carbon present in the metal, and as pointed out in Chapter III an increase in the amount of graphite may be brought about by increasing the silicon content of the metal by altering the mixture in the cupola. This procedure will generally have the desired effect.

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